THE THINKING MACHINE

THE UNIVERSITY OF CHICAGO PRESS, CHICAGO
THE BAKER & TAYLOR CO., NEW YORK; THE CAMBRIDGE UNIVERSITY PRESS, LONDON; THE MARUZEN-KABUSHIKI-KAISHA, TOKYO, OSAKA, KYOTO, FUKUOKA, SENDAI; THE COMMERCIAL PRESS, LIMITED, SHANGHAI

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THE UNIVERSITY OF CHICAGO

SECOND EDITION

THE UNIVERSITY OF CHICAGO
PRESS · · CHICAGO · ILLINOIS

SECOND EDITION SEPTEMBER 1932

COMPOSED AND PRINTED BY THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U S A.

PREFACE TO THE SECOND EDITION

BOOKS have been written about the natural history of bees and beavers and apes. This is a book about the natural history of human nature. It is not a book about philosophy for philosophers. It is a plain and straightforward statement for ordinary people of what another very ordinary sort of man who has considerable experience with the mechanisms of human life and how they work thinks about it all.

We all want to understand human nature better, because it is our nature. The better we understand it the more likely we are to get along with ourselves, our neighbors, and our surroundings in general. We want to make life more worth while, to get as much out of it as we can and to put as much into it as we can, to make a better living and to have as much fun doing it as possible. We need to know how we live, what the apparatus of life is and how it works, in order to make a better job of it.

The second edition has been critically revised throughout, with correction of some errors, short additions to the text, and new titles in the Readings. Several passages have been rewritten in the light of recently published researches.

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PART I

MECHANISTIC SCIENCE

CHAPTER I

OUR PROGRAM

THE theme of this work can be very simply stated. We want to know how far we can go in the study of human nature by the methods of natural science.

Science is commonly described as mechanistic. What is meant by that? Are the natural things and events which science studies all machine-made? What are machines, what kinds of products do they turn out, and how do they do it?

Natural science is called mechanistic because the chief end of scientific studies is the examination of natural mechanisms and how they work, and a good scientific account of an event includes the story of its natural causes and results and the physical machinery that is working to bring it about. So far as human conduct is open to scientific study, this is what we must try to do with it. It is not a hopeless quest. We know this because considerable progress in this direction has already been made.

The ancients set a god or a fairy in the thunder cloud, the volcano, the sea, the soil, and every growing thing to make them behave according to his whim. Most of us nowadays feel that we can get along without these petty gods because natural things do not behave capriciously and we have learned some of the laws of their action. Except perhaps the case of living things where in some places the little fairy still lingers.

Even the human body contains a great many undoubtedly mechanical contrivances, levers, force pumps, electrical generators, and so on, and our very extensive knowledge of these vital mechanisms gives the scientific foundation for the practice of medicine and for carrying on the ordinary business of life more efficiently.

Is it really true, then, that all human nature is machine-made? To put the question another way, Is there a real science of human biology? If so, how far can it go into human nature? Into the bodily organization? Yes, we all agree. Into what the body does, how it behaves? For part of this there is again general agreement. But we think that we do some things because we want to and we sometimes do other things that we don't want to because we think it is right. Has human biology anything to say about that? Not if our alleged will-power is an act of magic that does not tie into the rest of our behavior in cause-and-effect fashion. Learning the laws of nature is our only way to get control of natural processes, including those that go on in our own bodies; but it cannot give us a particle of help in voluntary control of behavior if volition is not a natural event.

Our only hope of living more comfortably and making our personal and social adjustments more successfully lies in a better understanding of how to do it and what to do it with. The elements of this problem are partly spiritual, partly social, partly physiological, and partly the nature of the physical world within which all of these things are set. These elements are inextricably interwoven in the flowing network of events that is life as I must live it. Can

natural science help us to disentangle these threads of cause-and-effect sequences or are they woven by Clotho or some other Fate over whose caprice we have no control?

We want to find out what the actual facts are about the relations of the spiritual life to the mechanisms described by natural science. So far as possible we shall attend to relatively simple matters of common experience. If we can find a workable way to handle these by rules of common sense and scientific investigation (which at its best is only refined common sense), we may find that the spiritual life is not so far removed from the biological life as we supposed. Indeed, we shall see that the idea of mechanism properly understood and rigorously applied gives a practicable approach to the study of human nature which takes full account of the immeasurable difference between men and other animals and is, in fact, the only possible approach to these problems from the scientific side.

That nature which science studies has been defined as the sum total of human experience. This enlarges as our experience expands and at the most it is a finite quantity; it cannot reveal the infinite. It follows that the deductions of natural science will never take the naturalist (as naturalist, not philosopher) to the end of the trail, to any ultimates, or to any absolute truths. Our aim here is to go as far as we can by this method and to stop well within the limits set by such a program. The underlying philosophical questions about the origin of things, the purposes and ends of things, and the ultimate nature of things lie beyond our present horizon.

This is mentioned here at the start to make it plain that we are not proposing to dabble in metaphysics. A mechanistic analysis of nature, of vital processes, and of spiritual experiences (if this be possible), if soundly based on verifiable factual evidence, is good for what it is good for—that is, for science and for practical adjustments to the world in which we live. It stands on its own feet quite apart from speculations about what lies beyond and behind our naïve experience. It may be consistent with almost any kind of philosophy—idealism, materialism, realism, positivism, pragmatism, or what you will—or with no philosophy at all—agnosticism.

The doctrine of relativity represents the last word of science up to date. And the discovery of the relations of things to one another is the first step toward a practical working knowledge of them—and perhaps the last step that natural science can take. At any rate, it is a big-enough theme to keep scientific investigators busy for a long time to come.

Those humanists who are so perturbed by the scientific dissection of the human personality because, as they say, science has no values and the spiritual life is unrevealed by even the most skilful vivisection, may quiet their fears. No true values are destroyed or impaired by learning the truth about them. It is only the counterfeit coin that cannot stand the assay.

For the distress which mechanistic science seems to cause among humanists, theologians, and philosophers the mechanists themselves are not without fault. Scientific investigators have sometimes been in rather too big a hurry to make far-reaching philosophical generalizations from their pitifully fragmentary observations and to sponsor a half-baked materi-

alistic philosophy which is not only metaphysically inadequate, but is so manifestly one sided and out of touch with a vast amount of genuine human experience that common sense incontinently rejects it.

It is not at all surprising, when scientific workers themselves say that their mechanistic science implies a crudely materialistic philosophy, that those who prefer some other brand of philosophy should say, "Away with such a sacrilegious science!" But really these metaphysical questions lie quite beyond the scope of natural science. It is no job for the naturalist to try to square his data with metaphysical systems; but it is his duty to carry his observations and the deductions that can logically be drawn from them as far as possible, wherever they lead him.

The mechanical aspects of bodily and mental work are kept in the foreground throughout this book because this is the phase of the subject in which we are here particularly interested. Of course, these same events are interesting from many other standpoints, and the writer does not wish to be understood as thinking that these others are less important. In fact, this is not true; for my own experiences include appreciations, values, duties, and aspirations whose vital significance is more clearly and vividly apprehended from the viewpoints of art, romanticism, ethics, and religion than from that of science. But the "humanistic" aspects of these experiences are generally recognized, while their relations to the vital mechanisms are, I think, almost everywhere misunderstood.

Our present plan, accordingly, involves the examination of a considerable assortment of natural mechanisms, an analysis of the idea of mechanism as

viewed from the scientific side, a survey of the natural creation and growth of living machines, and an appraisal of the work of these machines, especially as we find them operative in human life and society.

The traditional idea of a machine as something passively acted upon by outside forces is all wrong. All machines make things, and they make them actively. They are creative agents. Some of them, like river systems and living bodies, also make themselves. The output of the human machine is very different from that of any other known mechanism. This is what we are here interested in, and so we propose a radically mechanistic analysis of human life and conduct and human experience in order to see how the methods of natural science work out in this most interesting and most difficult field of scientific inquiry.

We are not sanguine enough to hope for final answers to the great riddles of life, death, time, and eternity. But we are never going to get on with the practical problems of human adjustment by tucking them away in dark corners and trying to forget them. The spiritual life has generally been disowned by science, or if admitted to the household at all, only as an unwelcome foundling. It is our plan to look up the parentage of this orphan and find out whether its claim to a significant place in the human personality can be scientifically validated. Much remains obscure, and if we succeed only in pulling a few of the mysteries hitherto carefully shielded from the profane curiosity of naughty mechanists out into the full sunlight, it may be that others who follow us may profit by our mistakes and give us a better account of ourselves.

CHAPTER II

THE ORDER OF NATURE

WHAT NATURE IS

WHAT is going on in the world is of interest to all of us, for this is the world in which we have to make our livings and live the lives that we have made. There is no escape from this. The more we know about the world, the more likely we are to be able to adjust to it comfortably. The things going on are not all reported in the newspapers. Some of them which are especially significant for our problems of getting on in the world will be mentioned as we go on.

Primitive peoples knew so little about the world in which they lived that they led a hard life and a meager life. Our lives are not only more comfortable but they are richer, because, having learned some of the laws of nature, we know better what to expect and can make plans for the future. We also know how to make the forces of nature work for us.

When we know enough laws of nature we can predict what will happen—the next eclipse of the sun, whether a particular forty acres of land will yield more profit from wheat or rice, what is the probability if two deaf mutes marry that their children will be deaf.

With scientific weather forecasts the pilot of an airplane can drive his ship to the desired haven with

far less danger of being dashed to pieces by an unforeseen storm. With knowledge of bacteriology we cannot only protect ourselves from infection by germs of disease, but we can even use these same germs to make vaccines for us. These are ways of controlling natural forces by adjusting our behavior to them. We can make them work for us only by learning how they themselves naturally work and then playing one force against another.

In controlling nature we do not violate any natural laws or abolish any laws. We merely regulate the natural forces in accordance with other laws. We must know what these laws are to do this successfully. When we make water flow uphill against gravity by using a force pump we have not destroyed the force of gravity, but we have opposed to it a stronger force.

These are the two great triumphs of modern science—prediction of events and control of events.

The countless marvels of our scientific age which give us security, comfort, and satisfaction are possible only because the processes of nature go on in orderly fashion. Disorder, caprice, and pure chance have no place in the natural system.

The things that we call "chance occurrences" are not uncaused. There are laws of chance which can be found out by statistical studies of things whose causes are too complicated or obscure for us to observe, and these statistics often give us the clue for finding real causes.

Left-handedness occurs in about 4 per cent of our general population. Is it because people are born that way or because they are trained that way? A recent

statistical study of left-handedness in identical twins makes it very probable that in these cases, at least, they are born that way.

Things that happen "by chance" are not disorderly. If they were so, they could not be handled with the elaborate mathematical technique which the statisticians use with so good results.

Nature is by *definition this orderly system of* things and events. Anything or any experience that does not fit into this unitary and coherent system with natural causes and natural consequences is not natural, and natural science cannot do anything with it or about it.

MECHANISM

A man-made machine delivers standardized products because it too works in accordance with natural laws, uniformly under standard conditions. Everything that it does goes on in accordance with definite rules that we embrace under our laws of cause and effect. The same cause is followed by the same effect. It always is. That is why we can standardize our machines and their products and depend on them.

These truisms are worthy of a moment's further attention. The outstanding feature of well-built machines is their reliability. You trust your watch, your car, your automatic telephone. This is because they work according to uniform natural laws that their inventors have found out.

All nature works according to these and similar laws, and throughout the whole natural realm there is only one system of such laws so far as we know. This means that all natural events are interrelated

in a single system of cause-and-effect processes. This is the great contribution of modern science—law, not magic.

This cause-and-effect relation of things is the most important natural law that we have, for it underlies our fundamental conceptions of the system of nature. This is what we mean when we say that nature is mechanistic—simply that it is orderly like our machines and that we can rely upon its system as soon as we learn what it is.

Natural events are mechanistic because they are results of causes just as wireless messages, steel rails, and other manufactured products are. We can predict their future courses as soon as we know the laws in accordance with which the mechanisms work, and then we can adjust our own behavior to them. In some cases we can control their courses, making steam run our locomotives and sunlight print our pictures.

Someone has pointed out that we now live in a tenth-of-a-second world, for this is about the time it takes a human voice to pass from a radio sending station to the most distant receiving station in the world. So this is a mechanical age. We have been told this a great many times, sometimes pointing with pride, sometimes viewing with alarm.

But all ages have been mechanical ages. The chief difference between the Old Stone Age and the age of wireless and talking pictures is difference in the machines employed by men and in their control of natural mechanisms. Hand work in chipping a spear-head out of flint is still mechanical work. The hand

is a machine. So is the rest of the body that gives the hand its cunning.

Even back of this there were machines before there were men. The sea is a machine that scours channels through rock-bound straits and grinds down cliffs of granite. A river system is a machine that may wear down half a continent and spread it over the bottom of the sea.

A survey of the world and its history reveals natural mechanisms in action everywhere and all the time. The whole natural universe is a machine. That is why we call it a cosmos, an order, not a chaos. Its parts are all mechanistic in their action.

The popular idea of what machines are is too limited. When we come to fit man-made machines into the system of nature we find that they too are parts of the cosmic machine. Our notions of mechanism must be enlarged as our outlook on nature is extended. By mechanism, accordingly, we mean everything that shows machine-like order or system in its operation. We must inquire how far this mechanistic conception of the world actually works out in practice.

ROBOTS

The newspapers nowadays are running stories of mechanical men which can do much of our household drudgery for us and—better yet—may deliver our after-dinner speeches. This reminds us of the popular play of Capek where the stage characters are robots, clever mechanisms that look like men and act like them, but are only machines. It did not come out very well in the end. The robots lacked something

which was necessary for doing the work of men and when they tried it the result was disaster.

Now we have before us in our survey of the natural world a mechanistic universe—galaxies, planets, rivers, molecules, electrons, plants, animals, men. Are they robots? Or perhaps all but you and me?

The attempt has often been made to interpret human conduct and experience on the assumption that we are all controlled by forces outside of us the way a child makes his jumping-jack perform, that we are, in Plato's words, "puppets pulled by strings." That sounds foolish, for our feeling of power to control ourselves and other things is a very direct experience and one that gives us real satisfaction. Furthermore, we have plenty of objective evidence of the reality of this control in the history of invention, of progress in science and art, and of the evolution of the machinery of the social order. Is this all an illusion?

There are some biologists, psychologists, sociologists, and philosophers who seriously think so. But this kind of mechanistic science when applied to human biology seems also to lack something. It does not cover all the facts of our experience. Later we shall come back to this point and inquire what is lacking and whether the missing parts can be supplied within the natural realm or must be sought elsewhere. For we cannot dodge these problems if we plan a comprehensive survey of the nature of the world and of human nature.

Before attempting to answer these big questions let us examine more closely just what we mean by mechanism in general and in particular by mechan-

istic control. The controls of an airplane are worked from outside the mechanism, but if these controls were not geared in with just the right kind of internal apparatus the ship would not respond to them properly. And as we go to still more complicated mechanisms in the living body, the internal controls come to play the dominant part.

CHAPTER III

CAN A MACHINE THINK?

OF COURSE not, almost everybody says at once. Then a thinking machine is a contradiction, a chimaera, or some other sort of fabulous monster.

KNOWLEDGE-BY-DEFINITION

Now, why do we say offhand, "Of course a machine cannot think?" Is it not because we have been accustomed to define a machine as something that does not think and thinking as something that is non-mechanistic? Having adopted this definition, explicitly or implicitly, the conclusion follows quite logically. Obviously, if by definition a machine cannot think, then anything that thinks is not a machine. Q.E.D.

But a syllogism which is perfectly valid logically may be wrong and utterly absurd factually. It is bound to be if the premises are wrong. If I define a man as a biped without feathers, then a plucked chicken is a man, as was proved, so the story goes, to the discomfiture of Plato a long time ago.

Stefansson has written a piquant little book (with his tongue in his cheek, I suspect) in which he shows that knowledge-by-definition, or what he calls "absolute knowledge," is often more convenient than knowledge painfully acquired by observation and experiment. The acquisition of factual knowledge is a

great deal of trouble, and we are never absolutely sure of our facts. We are constantly revising our facts about atoms, electrons, nebulae, evolution, and heredity.

It would be much simpler if some eminent authority or the state legislature would decree in advance what we must believe about these things. Then our settled body of knowledge would not be continually upset by embarrassing new observations and theories, our scientific investigators could devote themselves to more gainful occupations, and our education and propaganda would go on more smoothly.

Indeed, mankind has always striven to attain this happy state of settled calm. Thinking for one's self is too much trouble. We let the pope or the king or the schoolmaster do it for us. We have very elaborate machinery for defining and diffusing this "absolute knowledge." From the earliest days of which we have record, traditions and mythologies have grown up which supply a vast body of knowledge-by-definition.

MYTH AND HYPOTHESIS

In the golden age of classical antiquity it was thought that sunlight was controlled by Helios, a god who did as he liked about letting us have any sunshine. We have now dispensed with Helios, though it took over two thousand years to find out that sunlight does not come by the caprice of a god but according to natural laws. He was a very comfortable god to have around before the laws were discovered, but afterward he was a nuisance, and it would be very hard to reinstate him now by an act of the legislature.

But when the physicists undertook to complete their explanation of how light is transmitted from the sun through apparently empty space to the earth they ran into unexpected difficulties. If sunshine is a natural process, presumably it is mechanistic; but nobody knew what kind of a machine it is that carries it at the inconceivable speed of 186,000 miles a second. So they invented an imaginary machine and called it "luminiferous ether." It looks now as if we may have to banish the ether along with Helios. It is a very satisfying hypothesis for some of the facts, but it does not fit all of them, so it must be either revised or given up. Facts have an inconvenient way of disturbing our most cherished beliefs and hypotheses.

Myths and hypotheses represent knowledge-by-definition. The myth is held to be true because everybody believes it and has believed it from time immemorial. To doubt is impious. We have plenty of them still and they are taken very seriously, else why is there no room No. 13 in most steamships and hotels? The old ones persist with great tenacity, regardless of evidence, and new ones are forming all the time. Within the memory of men now living the gulls of Great Salt Lake have been sanctified as religious omens and the story of the origin of this myth and the associated taboos has recently been written up by Professor Kimball Young.

The hypotheses of the indivisible atom and of the luminiferous ether have also arisen within relatively recent time and the history of their origins is clear. One of these has already been abandoned; the other is in question.

How shall we distinguish the myth from the hypothesis? It is not always easy, sometimes impossible. Perhaps the best way is to say the myth is held as an end in itself; it is static. The hypothesis is held provisionally as a means to an end; it is dynamic. Both are based on evidence or some experiences or other; but the evidence is held subject to revision in the case of hypothesis and révision is resisted in the case of mythology.

Here are two bodies of knowledge-by-definition: one the beliefs supported by tradition; the other, hypotheses provisionally accepted. There is a third large body of current beliefs which are supported by formal edict of a legislative authority. We do not refer here to the ordinary laws of the land or to religious ordinances that regulate conduct, like the Ten Commandments, but to articles of belief or statements of factual knowledge such as are found in the creeds of many churches, in the pronouncements of the medieval Holy Inquisition and in the unholy inquisition established more recently in some state legislatures of the United States of America.

The Credo, or statement of belief, such as belief in the age of the earth or belief in the theory of evolution, should be based on evidence, and this is a task for science. The question is not what we must believe because somebody says so, but what we may believe in the light of human experience. We may go as far as we like beyond this in terms of faith; and it is better that our faith too be founded on knowledge. At any rate, the faith must not contradict experience. All belief contains some element of faith, even though it be merely faith in the stability of the

order of nature; and every belief should be supported by all the knowledge that we can get about it.

These three bodies of knowledge-by-definition make up a large part of our current beliefs. The modern *scientific attitude does not demand the summary* rejection of these beliefs, but it does insist upon their critical examination in the light of all available evidence.

LOGIC AND SCIENCE

Now, knowledge-by-definition is not always to be despised. It is, as Stefansson says, often very convenient. But we must be careful not to confuse it with knowledge-by-experience, or factual knowledge. Suppositions or postulates set out for purposes of argument are legitimate. The scientific hypothesis is such a supposition, not factual knowledge.

Mathematical reasoning is not based on factual observation or experience, but on postulates, and one may make any postulates he likes. They do not need to be true. The mathematician may use infinitesimals, a fourth dimension of space, or any imaginary thing that nobody has ever experienced. The only demand is that from the postulates chosen the argument must proceed with faultless logic. Bertrand Russell, with characteristic impetuosity, says, "Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true."

Mathematics is generally regarded as a highly specialized department of logic. It is not a natural science, for this last must be based on experience. It too must use faultless logic, but the logical process

must start with facts of experience, not with imaginary things.

THE RELATIVITY OF KNOWLEDGE

Science has no absolute knowledge in Stefansson's sense, or in any other sense. Our experience never gives us the full picture of nature; it is always partial and limited; so our knowledge is incomplete and relative. The doctrine of relativity, broadly conceived, is basic in all natural science; we have no universals, no ultimates, no absolutes, not in natural science. These belong in metaphysics or somewhere else.

SOME DEFINITIONS

Now, coming back to our mechanisms, living machines are so manifestly different from any dead machines that we expect them to do very different sorts of things. And this, of course, they do. Some of these things are very surprising to us. So are some of the things that dead machines do. Who could have predicted the behavior of radium in advance of its discovery? Or, for that matter, who could have predicted the properties of water from a knowledge of the properties of hydrogen and oxygen? The only way to know how a given kind of machine will work under some particular conditions is to find out by trying it. This has been said before, but it is worth repeating, and we shall come back to it again. Let us then not be too sure what any particular machine can do until we find out.

In the light of what has just been said it may be better, instead of asking, Can a machine think? to ask, Does any machine think?

Whether there is actually any natural mechanism that thinks or performs any other kind of mental work is a question of fact that can be answered only by finding out in the usual way by observation and experiment. And this will never be found out if we decide in advance on metaphysical or any other grounds that a mechanism cannot think and that thinking is a non-mechanistic performance. The reason why we are not yet sure whether thinking is mechanistic or not is that we have generally taken it for granted that it is not, without careful inquiry into the facts in the matter.

Progress toward a solution of this problem has been retarded more by preconceptions and by illogically putting the answer to the question in the formulation of the problem than by all the actual difficulties of the necessary observations and experiments, great as these are.

Now, of course, we cannot get away from definitions in scientific or any other kind of reasoning. We must try to make plain what we mean by mechanism and by mind before we can even begin our search for evidence whether mind is mechanistic. And we must avoid making definitions that prejudge the question that we are asking.

To recapitulate, by "machines" we mean material structures that perform work by natural forces, that move matter and energy against resistance, that get their material and energy from natural sources, and that deliver natural products—either material or energy or both in forms different from what they were before they were acted upon by the machine. The

nature of the product will depend on the nature of the machine and the conditions under which it works.

By "mind" we mean here conscious experience, awareness of some sort. We shall get no help at all by redefining mind as unconscious behavior of something or as biological adaptiveness, or by hypothecating an unknowable unconscious mind, or by any of the other popular tricks of dialectic. For the awareness or consciousness that these definitions avoid is just the thing that we are interested in here. We are using the word "mind" in the ordinary or traditional sense, the common garden variety, our awareness of what is going on.

This description leaves many important questions unsettled. We have not defined matter, nor energy, nor mind. But we have described them so that by appealing to your own experience I think you know what is meant well enough to enable us to go on. This is the best we can do, for science has not yet arrived at satisfactory definitions of any of these things. We know a great deal about all of them and their relations to one another, but what they are in the upshot we do not know. Metaphysicians have given many answers, but they do not agree among themselves and none of them rests on adequate scientific evidence.

OBJECTIVE AND SUBJECTIVE

We have experience of machines outside of us and inside of us—our objective knowledge; and we have experience of our conscious processes—our subjective life. The two kinds of experience seem equally direct and immediate. What we want to know is, Do both

of them belong in the natural realm? If so, both are by definition mechanistic as we have used the word above, and we must look for the mechanism that thinks and feels, that has conscious experience.

And we shall not look in vain. Let us try to lay aside for the present all of our traditional ideas and taboos about the relations of mind and body and look the facts squarely in the face without prejudice or preconception.

CONSCIOUS AND UNCONSCIOUS MECHANISMS

Having adopted this method of approach to the problem of the thinking machine, it is obvious that we shall have to revise our conventional ideas about machines in general. We must enlarge our conception of mechanism to fit the larger task. A machine that thinks, as the human brain does, and invents an internal combustion engine must certainly be a different kind of a mechanism from the one that was designed by the thinker to do what he wants it to do. And it is different from a machine like a river that does not think and was designed by unthinking natural agencies. So far as we know no thought entered into the making of the river at any stage of the process.

Of course, it may be said that though the river does not think, gravity does not think, erosion does not think, yet these natural agents were all planned and created by an omniscient and omnipotent Creator who does think. Science cannot deny that this is true; but we have no scientific evidence that it is true; and we cannot use in our scientific work any ideas, however attractive, for which there is no evidence in our actual experience.

Human experience is limited. It will always be finite. It can never know the infinite; indeed, most people cannot even form a satisfying picture of it in imagination. That is why in religious teaching God is so universally symbolized by some imagery that lies within the range of experience, some sacred object, ikon, or similitude of a man. We cannot by searching find out God. The idea of God transcends science, and we cannot fit it into our scheme of natural science. The naturalist cannot prove it, nor can he disprove it. Natural science is silent on this question.

Doubtless there are many things that are real that no man has experienced, but these do not form part of natural science today. Some of them may tomorrow. Natural science had nothing to say about the rings of Saturn until somebody saw them through a telescope, or about X-rays until Röntgen in 1895 demonstrated them by taking a photograph with them through screens of wood, metal, and other things that are opaque to ordinary light-rays. So it goes on. Our natural cosmos enlarges with our experience.

If one wishes to go beyond experience by hypothesis, by imagination, or by faith, there is no scientific ground for objection provided he does not mix his faith or his fantasy with his observed facts. It was Carlyle, or somebody equally pungent, who said, "Mixing things is the great bad." This is so sometimes, and this is one of the times; for the progress of science, its emancipation from mythology and superstition, its very existence, are dependent upon getting the facts by actual verifiable experience. Natural science can deal only with experienced facts and hy-

potheses deduced from these by faultless logic. The other things mentioned have their places, and sometimes they help us out in natural science. Imagination, for instance, may give a clue where to look for new facts, but the imagined fact must not be allowed to stand in place of an observed fact.

ACCEPTING EXPERIENCE

We accept our experience as it is, and we try to enlarge it as rapidly and as far as we can. This means that we accept the universe—our universe as we know it. It was Carlyle again who said, "Gad, you'd better!" But this does not mean that we are complacent about it. Carlyle himself surely was not. There are some things about this universe that we don't understand and other things that we don't like. The better we understand it the better we like it—in the long run. The things that we get peevish about are generally things that we could adjust to if we knew how. We know just enough about earthquakes, tornadoes, floods, laziness, juvenile delinquency, and disappointed ambitions to be dissatisfied with things as they are.

This little knowledge is a dangerous thing only if we rest our case here and then throw up our hands. If we fix our attention on all these disagreeable things and brood over them, of course our world is out of joint and we are all going to pot with it. Indeed, there are so many people who find it easier to grumble than to smile that anyone with a facile pen can extract a good living from the newspapers by calamity howling and viewing things with alarm.

A certain amount of calamity howling in the news-

papers may be a necessary step in waking a slothful public up to the necessity of doing something, but the men whom we honor most in the end are the people who tell us what to do and the people who do it. This goes, whether we are dealing with control of rivers, street traffic, or personal conduct.

If thinking is mechanistic in the sense in which we are using the word, then there is a fair prospect that we can do it better the more we know about the process and the apparatus that does it. This is the way we learn to get other natural processes under control, and it is as good a plan for getting ourselves under control and for the control of social movements. *Some of life's tragedies are unescapable, but most of* them are the direct results of our own blundering. Let us take a simple illustration.

A group of pioneers enter an unknown country and develop farms and orchards in a fertile river valley. They do not know that the river is subject to periodic floods. Ten years later the river overflows and destroys everything. They replant and rebuild, and the thing is repeated decade after decade. They now know what to expect.

There are two ways of reacting to this situation. One community goes on generation after generation true to form; the fixed habits are not changed. With each recurrent devastation some cultivate resignation, others curse. Nobody does anything about it. Another community may look backward and forward. They employ engineers to survey the river. Dikes may hold it and save the farms. If this seems practicable and the farms are worth the cost, they bond their land and build the dikes. Or they may

decide to live on higher ground and plant the flood-plain with annual crops in the hope of making enough in the good years to tide them over the disastrous seasons. Or they may move out.

The first community thinks the world is out of joint. It is they who are out of joint. They have not learned enough to adjust their farming to the river, or to control the river, or to move out. In short, their social machinery is inadequate to meet the situation and it breaks down. The river readjusts to fit its changing situation from year to year without knowing anything at all about it. These people know enough to suffer from their decennial losses and their chronic poverty, but not enough to correct them. They are more advanced than the river in one respect, that is, in their capacity to suffer distress from their misfortunes. But on this level of conscious adjustment they have not advanced far enough to make a comfortable living. Their behavior is not "adaptive," as the biologist would say, and such a community cannot survive indefinitely in competition with others who know how to adjust to their situations better.

The second community meets the emergency by making the social machine over. They invent a new social and economic process which fits the situation. This they do in terms of experience and foresight based on experience.

In all of these cases improvements come only by first adjusting our behavior to our universe as it is, by learning how it works and its natural laws, and then setting ourselves to change this world to suit our needs, or else, if we are not able to do this, then changing ourselves to fit the new situation as it is.

These are all practicable enterprises. We can do them as fast as we can learn the laws of nature and of human nature involved. These laws are uniformities to which we must adjust.

This is what makes nature mechanistic; and human nature mechanistic. For human nature is not as lawless as some people seem to think. Our business in science is to discover these natural mechanisms and how they work, and then to learn to use them in devising new mechanisms to do new kinds of work that we want to accomplish and so to enlarge our experience of nature still more. We can do this only by the exercise of our natural functions of observation, experiment, and reasoning.

A GLANCE FORWARD

We may now anticipate the chief conclusion of the following chapters. It will appear that the human body was made by natural processes of organic evolution and the human mind grew up with it. This improved mind is a function of an improved body. When our mentality reached a certain stage of competence it (and of course the bodily organs which do the mental work) became part of the causal complex which determines new kinds of behavior. It controls conduct mechanistically. A further step in the complication of the machinery of human life comes in with the elaboration of social institutions. These too arise naturally and become part of the apparatus of control of behavior.

This is our thesis—a mechanistic scheme that is broad enough to cover all human nature, including our spiritual life, without sacrifice of any of the values

which make our spiritual life significant. It is not an armchair speculation. It is based on scientific evidence, some of which will be presented in due course.

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CHAPTER IV

WHAT IS A MACHINE?

THE LAW OF MECHANISM

MACHINES are made of various kinds of matter—iron and wood and so on—and their work consists in moving this matter against resistance of one sort or another. This takes energy.

Matter and energy are the fundamental things with which we deal in mechanics, and the laws of machines are for the most part the laws of matter, its movements, and the energy required to do the work. These laws are found to interlock in a single orderly system where every event is caused by some other event. As soon as these interrelationships are adequately known they can be expressed in measurable quantities of various sorts. A working machine is matter in motion doing something—particular kinds of matter doing particular kinds of things and delivering a particular kind of product which is determined by the construction of the machine.

This is the conventional idea of a machine that most of us learned at school. Nobody ever told us what matter is in the upshot or what energy is. Atoms and atomic motions are as far as we got.

The new physics of the last twenty years has changed all this. We are now in the midst of a scientific revolution which is revamping our ideas of the

structure of the universe as radically as the scholastic ideas were upset by the revival of learning at the close of the medieval period, and it is doing it so rapidly that few of us can keep up with the movement. The atom is broken up into electrons and quanta of energy, entirely new conceptions of energy are current, and matter itself may ultimately disappear in a flux of energy.

Whatever may be the outcome of this revolutionary movement we are not likely to get outside the realm of natural law. New laws are being discovered and old ones scrapped with bewildering rapidity, but our cosmos is still orderly and mechanistic. Our ideas of what the mechanism is are radically changed, but the reign of law has not been disrupted. We still have atoms and molecules, calories, and all of the familiar tools of chemistry and physics. Most of the old laws still apply in the field within which they were formulated. When new facts come to light the old laws must be corrected or supplemented.

In our survey of machines—dead mechanisms and living mechanisms—we shall use the familiar symbols of the old atomic physics—matter, energy, space, and time. I do this because these are the thought-forms in which most of us have been brought up. They are conventional symbols which we all know something about, and they are adequate for our purpose. They do not take us to the end of the story. For that these symbols must be reformulated in terms of another set of abstractions—electrons, quanta, and space-time.

Very well. Let someone else do it. Many people more competent than I have already tried it; you

will find an interesting example in Bertrand Russell's *Philosophy*. We do not need that here, for all that I wish to bring out is that our natural cosmos is mechanistic—all of it—and that as our knowledge of this cosmos enlarges the essential unity of the natural system becomes more and more probable.

True, the mechanistic formulation given here is already out of date. But Mr. Russell's will be out of date next year too. The principles which we are here illustrating are quite independent of the details of the actual mechanisms operating. These we know only in part in any case. But in so far as we do know them they fit together in lawful ways, and the more we know about them the better they fit.

A well-known philosopher has recently described the output of a machine—of all machines—as "the passive product of external force," and this seems to be the popular notion. But it is nothing of the sort, as a little reflection will show. The machine itself, even so simple a machine as a lever, is doing something the while.

This idea is so fundamental that we must look into it further. If our philosopher could get a good grip on this basic idea he might revise his whole outlook on nature, and especially on human nature.

The mechanic is interested—and the mechanist too—in what is going on inside the machine, not merely in what is going on outside. A thorough knowledge of this interior mechanism and what it is doing will clarify our ideas about the machine and perhaps change radically our conceptions of what mechanism is and what it can do.

A SIMPLE MACHINE

Here is a rock a yard high in the wrong place. I felt pretty sure it was wrong, for it was in the middle of the railroad track at the mouth of a long tunnel and my train was just emerging from the tunnel. We stopped with a jolt only a few feet from the rock.

The track gang came up with crowbars and soon had the boulder rolling down the embankment. Archimedes' ingenious machine, the lever, came into play again and our express train passed on.

Three husky men with crowbars did what the entire train crew unaided could not have accomplished. The machine did it. A very simple little machine indeed, and yet a machine. If the rock had been bigger, too big for crowbars, a jackscrew or a pulleyblock might have done it; and these more complicated machines are again levers which apply the principle of Archimedes in still more effective fashion.

In the case of the more complicated machines everybody recognizes that the mechanism performs work and that the amount and kind of work depend on the internal structure of the machine. If you employ a mechanic to fix your car you expect him to know a great deal about internal combustion engines, transmission, gears, and wiring. If he has a working knowledge of what goes on inside the machine we call him a competent mechanic and we do not begrudge him his wages. It is the ignorant bungler whom we resent.

But when it comes to less complicated machines like crowbars we seem to think that it does not make any difference what goes on inside. And the same

thing is true of the most complicated mechanisms of all, some of which we have in our own bodies. We often allow the most unskilled ignoramuses or charlatans to tinker with our bodies as if it did not matter much what goes on inside or whether the tinker knows his trade or not.

INTERNAL WORK OF THE MACHINE

Again coming back to the simplest machine that I can think of, a crowbar, it certainly does make a difference what is going on inside the bar. We say that force is transmitted from the handle of the bar to the bit. How? Passively? By no means. Suppose the laborer throws his weight on the handle of the bar and hangs there. Nothing moves; he is not heavy enough. But the bar handle is pressing against his body just as hard as he is pressing on the bar; and at the other end the bit of the bar is pressing against the stone with just the same force and the stone is pressing back against the bar. Everything is in balance or equilibrium. Apparently nothing is happening. But are you sure?

That well-tempered bar is under strain. It bends a little. Release the weight and it springs back to its original form. It is trying to do so all the time while under tension. Every molecule is in active motion all the time and that motion is altered with every variation of the strain. With every change in the strain it is doing work, it is working hard, it is overcoming resistance—either internal resistance against bending or external resistance against the stone.

Let us take up the internal resistance first. Suppose the middle of the bar is improperly tempered.

The soft iron bends under the strain and it stays bent. The workman throws it aside. It is no good as a crowbar; "it won't work," he says. What he says is exactly right. The proper work of a crowbar is real work, real internal work of the steel which resists bending and springs back into place if forcibly bent. And its molecules must work in just this way. No other kind of work will do the job for which this particular machine is adapted.

Now another man throws his weight on the handle of the bar and slowly the rock begins to roll. The equilibrium has been upset; the weight of the rock is a little more than balanced by the thrust of the lever and it topples over. All this while the crowbar is by no means passively transmitting the energy from handle to bit. It is working internally. Its molecules are shifting their positions against resistance and they are overcoming resistance. Finally, their work is transferred to the stone, the resistance of its weight is overcome, and it in turn moves off the track.

Now you ask me to describe in detail just what this work is that is going on inside the crowbar while the track gang is sweating over it. Frankly, I do not know; my understanding of physics is not good enough to answer your question. But my friend, the professor of physics, can tell us a great deal about it. He says so and begins to write out his equations which I, being a mathematical moron, cannot understand. Even the professor sooner or later comes to a point where he says, "I really do not know the rest of it. I cannot tell you exactly how force is transmitted from one end of a steel bar to the other."

Never mind the details; it is clear enough that the

energy is not transmitted from one end of the bar to the other passively. Even in so simple a mechanism as a crowbar the internal structure of the machine is as important as its external form in determining how it works, and its work is a very active performance.

The crowbar, like every other machine, delivers as much energy as it receives—no more, no less. Nobody thinks that it creates any more power, but it changes the pattern of the energy that is fed into it. This change is very much more radical than appears on the surface. The weight applied at one end is transmitted through the steel bar by a very complicated series of molecular movements, the details of which we cannot go into, and it reappears at the other end of the bar as pressure against the stone. This pressure is more effective because this end of the bar moves through a smaller distance than the other end.

"Passive transmission" does not enter into the process at all. It is active transmission throughout. The product that is delivered at the business end of the machine depends in large part on the internal structure of the transmitting mechanism, whether it be a crowbar or an adding machine. Soft iron will not do the work of a crowbar, nor will an ordinary typewriter do the work of an adding machine.

The crowbar is working just as truly when it transmits energy from the man to the stone as the man's motor car is working when it transports him from his breakfast table to his job. In neither case does the machine create any more energy, but the machine applies the available energy to a kind of work that we want done.

THE PATTERN OF PERFORMANCE

Because we can write an energy equation and then prove experimentally that the machine delivers exactly as much energy as it receives, we are likely to overlook the fact that the machine itself is doing something with that energy. I may feed a coil of iron wire into one machine and it comes out paper clips; or I may feed the same wire into another machine and it comes out tacks all neatly done up in paper packages. The fuel bill may be the same for the two machines; the energy equations may be identical. Why is the product so different? Because the machines are different inside.

All machines illustrate this same general principle, that the internal work of the mechanism determines the product made by the machine. There is no "passive product of external force" to be found anywhere in the mechanical system. Different machines deliver different products because they are made differently and different kinds of things go on inside of them. This is not the whole of the story, of course. They must be fed with proper raw material and energy in appropriate form, and so on. But the part of this story that interests us most as mechanics and as mechanists is what is going on inside the machine.

A mechanic makes machines, or makes things with machines, or at any rate tinkers at it; and we all do more or less of this more or less well. What kinds of machines do we use? What kinds do we make? And do we care a tinker's dam what we are about while we are at it? It is worth looking into because we really do not want to bungle it, whatever it is that we are about. The poor workman blames his

tools; the good workman knows his tools, he takes pride in them, he may even love them.

Most of us apparently have entirely too simple notions of what machines can do. The mechanists believe in machines and pin their faith to them, and they, of all people, should know their tools. They are looking for mechanical explanations of everything, and what they cannot explain in this way they are likely to lose interest in. If now they have wrong ideas or too simple ideas of what machines are, they are likely to fail to come through with some of their explanations. They do not know their tools well enough and so it is not very surprising if they sometimes bungle their work.

This indeed is just what has happened to a number of mechanists. Their notions of mechanism are so crude that when they try to apply them to living bodies they break down. They are so obviously inadequate that when these mechanists try to prove that a man is the same kind of a machine as his motor car our everyday experience contradicts them at every turn.

Perhaps the trouble is that they do not understand the real essentials even of the mechanism of the motor car, and how then can they be expected to explain the infinitely more complex human organization in terms of so absurdly oversimplified a scheme? If the mechanists themselves start out with an inadequate understanding of the simpler mechanisms, their critics can easily pick flaws in their work, especially in the field of mechanistic biology. This has repeatedly happened.

We who call ourselves mechanists may well look

to our foundations. Some of us undoubtedly need to clarify and to enlarge our own ideas of what mechanisms are.

Most biologists are mechanists, at least up to a certain point. Man is an animal (whatever else he may be too) and human biology, by common consent, is also mechanistic, again up to a certain point. Now, as a biologist I am a mechanist, and a more radical and thoroughgoing mechanist than some of my colleagues in the field of human biology. I am convinced that, if we grasp a few simple general principles of ordinary physical mechanisms that very often seem to he overlooked, we can find mechanistic laws in biology, and even in psychology, of far more comprehensive scope than many biologists and psychologists seem willing to grant.

It is true—and this must be emphasized at the start—that the plan here adopted requires a very considerable change in the popular conception of what machines are. We are not proposing a new definition of mechanism; it is merely an analysis of the popular idea and of current scientific usage, with a broader application of this analysis than is customary.

If recently discovered facts or new interpretations of old facts do not fit into the traditional mechanistic scheme of things, one may either say that the new things are non-mechanistic or he may revise the old ideas of mechanism so as to include the new data and interpretations. It seems to the writer that the second method is more promising because it fits our previous scientific experience better. This is why so much attention is paid to inorganic mechanisms in this book on human nature.

The new physics cannot use the old mechanical models of atoms; they do not fit the new facts. So some physicists are inclined to think that activities of electrons and quanta do not conform with mechanical laws, their movements are arbitrary, indeterminate, or "free." But Professor Lillie concludes that infra-atomic events conform with laws of determinism which differ from those of large masses of matter, and yet they are within the same order of nature. We shall come back to the question of determinism in nature in chapter xxv.

The progress of the biological sciences, and especially of physiology, is marked by successful attempts to explain animal behavior and human behavior by showing what are the mechanisms that do the work. These sciences are as mechanistic as mechanical engineering, and no great progress has been made in any other direction nor with any other technique. And yet the thing seems to break down at the finish—in the realm of what we commonly think of as the higher human activities, what we popularly call our spiritual life, that is, our adaptability, learning, inventiveness, imagination, and consciously directed behavior in general. Why?

Something is clearly wrong with the prevailing mechanistic conception of human behavior. Either not all of human life is mechanistic or else our ideas of mechanism in general are at fault.

Before throwing overboard our only practicable tools for the scientific study of man let us look farther into the real nature of the simpler machines. When we understand these better mechanistic biology may not be in so bad repute and the big problems of hu-

man life may not seem so hopeless. And then we may get on better in our business and bring up our children better if we know more about the living tools with which we must work in these absorbing vocations.

We have, in fact, found out how to control some of the forces of inorganic and organic nature by learning the rules or laws of the mechanisms through which these forces work. We have not created any new energy when we do these things, but we have created new patterns of performance of energy. We have made things behave in ways that they did not behave before. We have proved that this is practical. Is it an idle dream to hope that we may make further improvements in social control and self-control if we learn more about the mechanisms of social evolution and self-culture? We shall never know unless we try.

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CHAPTER V

NATURAL MACHINES

IN THIS chapter we shall review a few characteristics common to all machines and some of the rules of procedure which are followed in mechanistic science.

LAWS OF NATURE

Machines work according to rule without caprice or interference from outside the mechanical system. That is why they deliver a uniform or standardized product. This is just as true of natural machines like the solar system or a trade-wind as it is of the engine lathes in an auto factory.

So we have machines invented by men and machines that were not invented by anybody—natural machines. Both of these kinds of mechanism work according to natural laws. That is what makes them machines instead of supernatural or magical apparitions, ghosts, gnomes, demons, angels, or Olympian gods. No machine needs a spirit or ghost to run it or tell it how to do its job. That is why we can deal with it scientifically. The fundamental sciences deal with natural mechanisms and most of the applied sciences with artificial machines or natural machines under human control. This distinction is sometimes convenient, but it has no other special significance.

Invention of machines illustrates the method of natural science in all fields. We first find out as much

as possible about natural things and how they work. The rules or uniformities of behavior that we discover are the laws of nature. These laws are not somebody's commands like royal decrees or acts of Congress, nor are they immutable mystic absolutes. They are just our accounts of the way things actually work. So we change our laws of nature as fast as we enlarge our knowledge, as happened when we found out that atoms are not ultimate indivisible and unchangeable units of matter.

After we have correctly formulated our laws of nature we can predict what will happen, because nature is very methodical. Under identical conditions the same things happen. They always do. The reason why it is not always safe to dress for the day according to the weather predictions is that the weather man does not know all the conditions or all the fixed habits of winds and clouds and sun-spots and the other things that determine what is going to happen in Boston or New Orleans tomorrow.

CAUSE

This orderliness of nature is all that we mean in science by cause. We know nothing about any law of necessity that decrees the result of any cause. The cause of an event, as the naturalist conceives it, is not a statement of the fact that the thing has to work in this way; it is merely a statement of the fact that it does so. Nor is the cause a force that compels things to work out in some predetermined sequence. When a naturalist talks about a causal sequence he means an observed and verifiable uniformity in the course of events. And that is all he means. By uncaused

action he means things that do not fit into a unitary system of such orderly events. We may add that if there are such actions the naturalist does not know how to do anything with them.

The cause determines the result simply in the sense that our experience shows that something else would happen if it were not there. Determinism is simply another name for lawful or orderly behavior of things, for observed uniformities. It is the opposite of chance or haphazard behavior. It does not mean that somebody or something has determined or decreed that future events shall take place in some foreordained fashion—not in science. This is a theological, not a scientific notion.

Science is deterministic because nature is orderly, and that is why a scientific explanation of things enables us to predict future events. When we know more laws of meteorology we can predict the weather better. When something natural happens we believe that it did not happen by chance but that it has a cause. We also look for the physical instrument that did it.

LAWS OF EQUILIBRIUM

One thing all man-made machines and all natural inorganic mechanisms and all living bodies too have in common. The activities of all of them represent an upset of a stable equilibrium, that is, departure from a condition of rest or of uniform motion. The working of the machine is the expression of a natural tendency to restore the equilibrium or to arrive at some new equilibrium which does not involve the transfer of matter or the transformation of energy

against resistance, which is what we mean by doing work. For a technical account of the biological aspects of this subject see Lotka's *Physical Biology*.

We ourselves work to satisfy needs or wants. How long we work depends on what we need or want and how badly we want it. When our wants are satisfied we usually do not stop working, for we develop new desires and ambitions. Our complacency is still disturbed, our equilibrium is still upset. So we toil on. Most of us do, but there are some people who will not work at all as long as they have money in their pockets, not until they have spent it all. This is really a reversion to a very primitive inorganic mechanistic principle.

Every machine seems to act as if it wanted to quit working. It works as long as its affairs are unsettled and it stops working as soon as equilibrium is restored. The lever of our first illustration begins to work as soon as the existing balance is upset, and it stops working as soon as the forces acting on its two arms are equalized. Every other machine acts in a similar way.

ENTROPY

All the world seeks rest. Water seeks its level, and all forms of intense energy tend to run down to less strenuous activities. Energy which is capable of doing useful work is sometimes called "free," and this free energy is contrasted with "bound" energy of no practical efficiency. All forms of free energy tend to run down into uniform heat, or molecular motion, that is, into bound energy which can do no work.

Some natural philosophers have drawn for us a dismal picture of the ultimate degradation of all cos-

mic energy to a dead level of uniform heat with nothing going on anywhere different from what is going on everywhere else. The universe is running down like an unwound clock. This process is sometimes called "entropy," and is said to be the logical result of the second law of thermodynamics—so of course it must be true. But even so, Earth will not be as dead as the moon for yet many cycles, and in the meantime we can paint a prettier picture.

In the inorganic realm there are numberless local and temporary reversals of this general tendency of energy to run down from more efficient forms to useless uniform heat (this is reversal of entropy).

There are artificial machines that do this sort of thing, illustrated by an electric transformer which uses a part of the current fed into it to raise the remainder of the current from low to a higher potential. To do this is work, and part of the energy supplied to the machine is used up in doing it. The advantage of the transformer is that the remainder of the energy which is "transformed" to higher potential can do some kinds of work that the low-potential current cannot do. It can send wireless messages, for instance. The water of a quiet lake is at rest in relative equilibrium. The heat of the sun evaporates it and lifts it up to the clouds. This is work. By and by it falls down again as rain and the falling water can do more work. It can wash sediments to the sea or run a mill. After it has "reached its level" its work is done. It has returned to equilibrium.

Living things are reversing entropy all the time; this is their chief industry. Plant life, Prometheus incarnate, seizes the energy of the sun's rays and con-

stantly builds up its own tissue out of inert material, thus reversing the cosmic trend toward degradation. Animals use the plant tissues as food and step up the vital energies to a still higher level of efficiency.

All living bodies are transformers of energy. They work to build up very complex substances which have potential energy—like the accumulation of fat for future use—or they transform the heat energy derived from oxidation (combustion) of food or fat into much more efficient forms of vital energy, like nervous action and muscular work.

The average man in order to keep going has to get energy from his food equivalent to about 3,000 calories a day. That is, if this food were burned it would give heat enough to raise the temperature of 3,000 liters (about 795 gal.) of water 1°. If the man does more than the average amount of muscular work, he must either eat more food or else use up some of his reserve supply of fat and get the additional energy that way.

In the course of time there has been progressive improvement in power to do this sort of useful work by living mechanisms. The animal and plant kingdoms are today in the aggregate far more potent in subjugating the forces of inorganic nature and redirecting them in ways that are useful to them than were their ancestors whose history is preserved for us in fossils laid down millions of years ago. Mankind is doing this job of "creative evolution" more rapidly than any of his predecessors, and the history of his progress in replenishing the earth and subduing it is strictly biological history open to scientific study. As we live better—that is, more constructively—we live

more, we are more alive, the vital mechanisms are more efficient.

The human brain does the highest type of this sort of work known in nature, or, in other words, it does the most useful work in the world. Part of this is unconscious reflex adjustment; and, as we shall see, mental work comes in here too. By mental activity new machines are invented, like transformers and dynamos designed especially for this purpose. In short, the measure of human control over nature may be expressed very largely in terms of our ability to reverse the natural tendency for energy to run down to lower levels of working power. And our social machinery of manufacturing, industry, commerce, and government works in the same way on a higher plane. Perhaps this is the chief work of the mind when viewed from the standpoint of cosmic dynamics. But here we are far ahead of our story.

The problem of entropy is very complicated and recondite, and there are some naturalists who will not accept the simple statement of it here given, which is certainly very inadequate. It seems evident, at any rate, that organisms step up the gradients of energy change to forms which are more efficient for some kinds of work. And there are some physicists who think that our universe as a whole contains inorganic mechanisms for reversals of entropy on a large scale. The very powerful "cosmic rays" investigated by Millikan are supposed to be results of such action. On this view our cosmos is not running down, but it is potentially immortal at a high level of creative power.

MECHANISTIC CONTROL

The control of natural forces is one of the primary objectives of scientific research. In this way only can we get what we want. We can make radium cure some of our ailments and we can make the Mississippi River flow where we want it to, not over our farms. We can construct control works at the outlet of Lake Huron that will raise the level of the lake two feet any time enough of us want to.

This control is a real thing, and it is done by the machines that we have discovered or invented. It is possible because the forces of nature are not disorderly or capricious. The Mississippi River controlled itself in its own way long before man appeared in North America. The water acts on the channel, the channel reacts on the water, sandbars are built by the water flow, and they in turn deflect the flow. The river from its beginning is a system of natural forces whose balance or equilibrium has been disturbed and which is tending to return to equilibrium. Because conditions of continental elevation, rainfall, and so on are changing, the river is constantly doing new things in adjustment to new situations.

All natural and artificial mechanisms illustrate the same principle. Mechanisms are to some extent self-regulating. Otherwise they would not work. Some internal regulation, some measure of self-control, is characteristic of all machines. The laws of this regulatory activity, of this mechanistic self-control, are all natural laws. We know what many of them are.

Control of the course of events, then, is the business of all mechanisms. This is what machines do

with the energies and materials that pass through them; they make them over.

This control is manifested by the machine in two ways: first, control over its external surroundings, as when a passing railway train automatically sets a block signal against a train approaching it in the opposite direction; and, second, control over its own internal affairs, as when a safety valve on a steam boiler automatically releases pressure when it rises above the limit of safety. Natural machines present numberless similar illustrations of these two types of control that will occur to anyone, as, for example, control of earth tides by the moon and the automatic regulation of the flow of a geyser.

This sort of control is a fundamental feature of all mechanisms, as has been brought out before. Its great importance in our inquiry is the reason for restating it here; for we shall see that in living machines, and especially in the human machine, biological and social efficiency depend very largely upon the pattern and adequacy of the apparatus of control of behavior.

Control and creation are often cited as two things that cannot possibly be regarded as mechanistic. Self-control in particular is often regarded as a God-given prerogative of mankind alone. Natural creation we shall look into in the next chapter. Here it is clear that control is the most essential feature of all kinds of mechanism and that the process is universal throughout nature. What kind of control we get depends on the apparatus that is working. Living machines differ from dead machines chiefly in the peculiar ways in which the internal mechanisms of control regulate behavior.

SUMMARY

The general conclusion from this survey of natural and artificial mechanisms is that these are all contrivances to do some kind of work and deliver some kind of a product. They are active, not passive. Dead machines and live animals are alike in this respect. The energy and the raw materials are all taken from outside the mechanism; that is, they were there in some form before the process of manufacture began. They come out in a different form, and the work of the machine is to effect this transformation. Part of the energy supplied is used up in the machine to do the work. From the standpoint of the efficiency engineer it is "wasted" and goes off as useless heat of friction and so on. The rest of the energy comes out with the product. In some cases the useful product is nothing but this energy, as in a dynamo.

Some artificial and natural machines step up the energy from a low level to a higher level of efficiency for some particular kind of work. A steam engine does this, so does the sun when it evaporates water from the sea to the clouds so that it does work of erosion as it runs back to the sea. All organisms do efficient work of this sort, and the higher animals are especially proficient in this kind of constructive activity.

The total energy expended by a man doing heavy muscular work is about two horsepower, most of which is used internally. A. V. Hill estimates that about 25 per cent of the total energy used may under favorable conditions come out as useful mechanical work, and this indicates that the human body is a

more efficient machine for this kind of work than the average steam engine. But some men do other things besides muscular work which are much more useful and require the expenditure of far less energy.

The outstanding feature of all mechanisms is control of the course of events that go on within them. How this regulation or self-control is done depends on the structure of the machine. The pattern of this internal control determines the output of the machine.

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CHAPTER VI

HOW MACHINES ARE MADE

INVENTION

A MACHINE may be invented to make almost anything provided there is demand for enough things of a kind to justify it. Even good works of art in wood, metal, glass, porcelain, fabrics, pictures, can be turned out a thousand at a clip provided a thousand people want the same thing. People do want the latest thing in mechanical conveniences, speed and comfort of travel, household decoration, and personal adornment.

The invention of machinery follows just as fast as people make up their minds what they want to manufacture and then find out the natural rules or laws with which they must conform in order to design the tools. Wireless transmission of speech and a moving picture of the speaker come when people know how to learn the rules of the game and are willing to try hard enough to do it. We harness natural mechanisms to do our work for us. The winds and rivers run our mills, steam runs our railroads, and electricity puts a girdle round about the earth in less time than it took Puck to make the circuit for Oberon.

A man invents a machine because he wants to make something with it that he could not have if he did not find out how to make it. What he makes is a novelty, something that did not exist before—a tele-

scope, a dynamo, or an electroplating outfit. The invention is a creative act, the fabrication of the machine is a creative process, and the work of the machine as it delivers its product is creative.

MAKING A RIVER

Natural machines, not made with hands, have a different origin. Take a river system. Rivers are born, grow up to maturity, pass into old age, and finally die. This analogy with a living body is not a mere play upon words; it helps to understand both rivers and organisms, as we shall see later. So when a geologist calls a river "young" or "mature" or "old" he is not telling a fairy story. Most dead rivers have died a "natural death" of old age; but sometimes a river is killed "by accident." This happened in North America in scores of instances at the close of the ice age, some twenty thousand years ago. The channel of a lusty preglacial river was choked by advancing ice or by glacial débris upon the retreat of the ice sheet. The water was diverted. It cut a new channel to a new outlet, and the old channel, left empty and useless, tells the story of its former history so plainly that anyone may read it. The favorite outdoor sport of one of my geological friends is the mapping of "fossil rivers," abandoned water courses whose careers were terminated in their prime by movements of the continental ice sheet of the last glacial period.

The Mississippi River is a mature system. It has been growing a long time, and the history of its origin and development is tolerably well known. It is possible to predict, in broad outline, what its future

career will be like, because rivers are made by natural processes which we understand pretty well. Knowing how rivers were made and the laws of their flow, their erosion, their floods, and their sediments, we can not only predict something of their future behavior, but we can control that behavior, to some extent at least.

The Mississippi has a bad habit (from our standpoint) of overflowing its banks. We can correct that habit any time we want to. It will be an expensive proposition. The live questions are whether it will be worth what it costs and who will pay the bill.

The Mississippi River was not always there. It was created. Probably not by Jupiter Pluvius, but by something. It did not just "happen along" as an uncaused accident. And it was not made out of nothing. We know pretty well how it happened to come, what the causes were, and what it is made of. When it made its appearance it was something new under the sun. Nothing exactly like it had ever before existed in our cosmos so far as we know.

When this river began it had no delta. That came later. Now it has a big one. The delta too was a new thing. It was not something kept in stock ready made from the foundation of the world in readiness to be set out in its place at the proper time. It was made to order out of materials at hand which before that time were not a delta, just as a tailor makes a suit of clothes out of bolts of suiting and lining, spools of thread, buttons, and so on. This suit is cut to fit a particular man (usually he is very particular about it) as he is today, not as he was when a slender stripling or as he will be when he gets old and tubby. So this delta was made to fit a particular river at a par-

ticular time. The river made it. It will keep on changing it to fit the river as it grows older. This river is now carrying a million tons of mud to the Gulf of Mexico every day. Most of that goes into the delta.

Here is a natural machine that arose in a natural way and is now engaged upon a big manufacturing enterprise—wearing down a continent, transporting it to the sea, making mountain ranges over into fertile plains, and in short making the map of North America what it is today and what it will be tomorrow.

How was the river made? By continental uplift, rainfall on the land thus lifted out of the sea, the configuration of encircling hills and mountain ranges, and ten thousand other things, all working together in a series of events which are discoverable by scientific study.

NATURAL CREATION

The point we want to stress here is that natural machines have natural origins. And they are real origins. The making of a river or a delta is a creative act, not the mere uncovering of something already there. This is just as true of natural machines as of those invented by men. Nature invents new things to fit new situations as truly as men do. They are really new in both cases.

All machines make things, and a new kind of a machine will make a new product, a novelty, something that would not be made if the machine were not operating. New natural machines, like mountain ranges, rivers, deltas, are coming into our world from time to time. Before there were continents there were no rivers, nor any laws of river erosion.

All natural processes are constructive. Even the

destructive action of a river when it wears down a mountain range is creative, for all the material eroded away is used somewhere to make something else. Our natural cosmos as a whole is a creative mechanism. It is constantly making itself over, and it is doing it differently and making new products from time to time.

Of course, these things are not made out of nothing. That would be an act of God, not of nature. Matter can perhaps be made out of energy and energy out of matter, as the new physics teaches us, but we have no evidence that either of these things can be made out of nothing at all by any natural process.

The making of novelties seems to be nature's chief industry. Nature is a process, not an inert thing. The most important laws that we have in science are the laws of change; laws of regulation, control, growth, and evolution; laws of natural creation.

There is nothing mystical or magical about this. This is the way nature works. The first job of a naturalist is not to tell what the ultimate nature of things is and where our cosmos came from, but to find out what nature is doing and if possible how these things are done and what they are done with. And this takes us back to a study of origins which we shall follow as far down the line as possible.

Now, of course, we are permitted to ask, Where did the cosmic stuff come from in the first place, and the energy? I don't know, and I don't know anybody else who does know. Science has no answer. We accept nature as we find it—a going concern. Science has its hands full at present with the problem of how

nature works, and it has nothing to say as yet about the origin of it all and the finish of it all.

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PART II

MECHANISTIC BIOLOGY

CHAPTER VII

LIVING MACHINES

A GOOD LIVING

LIFE is just one thing after another.[1] The one thing is getting; the other is giving. The same thing is true of any machine. You give your car gas and it gives you mileage.

The rules of this alternation are very fundamental and there is no possibility of evasion or beating the game. For the vital process is the interaction of organism and environment, which means getting things from our surroundings and giving them back again. Our personal problems, then, are to get what is most worth while and so to arrange our giving that both donor and recipient will profit most by the transaction. Our skill in resolving this problem is the measure of success in commerce and industry and in the satisfactions that we get out of life in general.

This theme might be developed by the moralist or the merchant—in fact, the younger Rockefeller has done so from both of these standpoints—but it is really much wider than any of these. It is a fundamental law of life wherever we find it, and it gives us our measuring rule by which we evaluate life.

THE HIGHER LIFE

The trout is a higher organism than the water weeds among which it lurks and the bugs on which it

[1] "Il y a toujours quelquedam chose."—B. L. T.

feeds, for it can take more kinds of things from its surroundings and it can do more kinds of things with them. It can adjust to more varied situations and it can react to a bigger world in more individual fashion.

The trout receives more from its environment and it delivers more back to that environment. By the same token the man is higher than the fish and civilized man than the savage, for each of these can take more from nature and more effectively leave the impress of his own personality upon nature. The nation that maintains friendly co-operative relations with its neighbors gets more from them in commerce of commodities and ideas and it gains rather than loses by its exports. It exhibits a higher type of civilization. The public-spirited and socially minded individual lives a more productive and useful life. There is a biological reason for this. The life that these more co-operative individuals and communities live is higher, it satisfies more needs, it is richer, it has a better chance of survival in a social organization in the long run. This is because the personal and social machinery is more efficient.

We believe that this getting and giving is a mechanistic performance throughout the series. It is a matter of readjustment of the dynamic and vital equilibrium. Every natural and artificial machine does it more or less; living mechanisms do it more and better and progressively more and better as we pass from lower to higher members of the series.

THE DEFINITION OF LIFE

We have not yet found a perfectly satisfactory definition of life, but the best of them recognize this

principle in some way. Many years ago Herbert Spencer wrote this definition: Life is the definite combination of heterogeneous changes, both simultaneous and successive, in correspondence with external coexistences and sequences.

There are many pages of equally lucid exposition and much close argumentation, but when the verbiage is squeezed out it comes to this: Life is correspondence with the environment. Squeezing this expression a little more, we recognize that the live animal is constantly taking everything it can use from its surroundings. And it keeps none of it, not indefinitely. Sooner or later everything it gets—foodstuffs, energy, and its own pattern of behaving—it gives up again.

This eternal flux of the living machine differs from that of the man-made mechanism in several important respects. In the first place, those natural forces which would rust out and wear out a watch or a Bessemer furnace are used by the organism to nourish and support itself. It is self-repairing and does not wear out for a long time. In the second place, before it finally breaks down and is scrapped it creates new machines of the same design. Self-repair or self-preservation and reproduction are the two most obvious peculiarities common to all living things.

There are many others. Each kind of animals is adjusted to some special mode of life and in some particular kind of surroundings. Its body is made to fit the niche in which it lives, the environment with which it "corresponds." If the environment changes, the animals may perish if the adjustment or correspondence is too rigid, or the species may slowly

through many generations change its structure and habits to fit the new situation. This is evolution.

Or again, the animal may change the environment to suit its own needs. This is control. Corals do this when they build reefs, ants when they build anthills, beavers when they dam streams and dig canals, and men when they deforest half a continent and plant it in corn.

ADAPTATION

The meaning of the expression "correspondence with environment" and how the animal does make these adjustments can perhaps be made a little clearer by recurring to the analogy of the river. The water that runs is not the river, for that same water when it gets to the sea is no river at all. Nor is the channel of the stream the river, for if the water is diverted to a new channel the bed and banks are just the same but the river is gone. Evidently the river is the system as a whole in action. It is the going concern. It is the water washing down sediments, cutting away its banks, laying down sandbars, and building its delta.

Rivers, as we have seen, are born and grow up and die. The young river has steep gradients and is eroding its banks rapidly. The mature river runs through a wide valley with gently sloping walls and it does less erosion. It carries less sediment. The senile river has worn its drainage basin down nearly to sea-level and meanders through floodplains choked with sediment. Like an old man, all of its activities have slowed down. The "vitality" of the river is greatest when it is young and doing the most work.

The river shapes its own destiny. It creates its

own form and patterns of flow. The water acts on the banks and the banks act on the water. The changes constituting the growth of the river are produced by its own action, but the pattern of these changes is influenced by all that is going on outside—rate of continental uplift or subsidence, rainfall, and countless others.

The river is described mechanistically as a system of matter and energy of various kinds whose equilibrium has been upset. A geological change, like the elevation of land out of the sea, disturbs the existing balance, and rain which before fell into the sea where it was at rest now falls on high ground and as it finds its way back to the ocean it does the work of erosion. While this is going on we have an interaction between a system of water channels and the physical geography of the drainage basin. The process adapts itself to existing conditions of topography and rainfall. Adaptation, then, is the process of return to a more stable equilibrium, a process which is completed when the drainage basin is degraded to sea-level. The river as a natural system disappears; it is dead.

Biological adaptation is the same sort of thing. Animals and plants adapt themselves so cleverly to changing conditions that some naturalists and many philosophers think that therefore vital processes cannot be mechanically determined, so they resort to mystical explanations that do not explain anything (entelechies and the like). Really this adaptiveness is nothing peculiar to living bodies. It occurs in all natural mechanisms; it is an incident in the process of equilibration everywhere.

Adjustment of behavior to changing conditions,

regulation, and adaptiveness in general are seen everywhere in nature. How the thing is done depends on the mechanism that is doing it. Living mechanisms do it differently from inorganic mechanisms and with much more complicated machinery, that is all.

THE VITAL MECHANISM

Some of the ways in which living machines differ from those which we use in our factories have just been pointed out. Most of these common machines that we are acquainted with make changes in the stuff to be manufactured, the raw materials, so that the finished product has the same stuff differently arranged. Take a simple illustration. Soapstone is a common rock that can be bought by the ton very cheaply. It is put into a machine that grinds it up very fine and it comes out talcum powder. The total cost of raw material and manufacture is trifling. It is now conveyed to another mechanism which mixes it with a little perfume, whose cost is also trifling, and packs it in decorative containers. The finished product is then sold with a handsome profit at from five cents to a dollar an ounce depending on the advertising skill of the vendor.

In the manufacturing process just described the machines themselves have not been changed at all except for ordinary wear and tear. But some of our machines do part of their own manufacture. The manufactured product of a first stage of the process becomes at a second stage a part of the machine itself which then delivers a different product. In an ordinary dictograph, for instance, spoken words are recorded on a roll. The machine may be so geared

that it automatically reverses itself. The manufactured roll containing the record now becomes a part of the machine which delivers the spoken words again.

Some natural machines like rivers carry this process of self-manufacture right through from start to finish, so that we may say that the whole machine is self-made. The same is true of all living bodies. All vital functions, including reaction to stimuli, growth, and reproduction, leave the structure of the machine different from what it was before.

Living machines, then, create themselves out of stuff that was before not alive, as we prove everytime we eat and assimilate a meal and every time a child grows an inch in height. In this they do not differ from rivers which also create themselves out of stuff that before was not a river. Rivers and dogs and men do it differently because they are different kinds of machines. It appears to be a mechanistic process in every case.

A machine works according to natural laws and so delivers a standardized or uniform product, provided the conditions of its operation remain constant. This is the result that we try to secure in most of our artificial machines. We want every carburetor of a Ford car to be near enough like every other one so that whether we buy it in Maine or Nevada it will fit any car of this make that comes along. And this the factory machines do for us.

But there are other kinds of machines that make individual products every time. The adding machine will solve the same problem over and over in just the same way, but ordinarily a different problem is given it every time and, of course, it delivers a different

answer. Under changed conditions the output of the machine is different.

In both of these cases the machine is working in accordance with natural laws. It will give uniform products under one set of conditions and diverse products under other conditions. Effects are different when causes are different. At no time have we got away from the natural laws of cause and effect.

Most natural mechanisms, like solar systems and river systems and tornadoes and guinea-pigs, are of the variable sort. The conditions are variable and their products are never twice alike.

MECHANISTIC BIOLOGY

These are all mechanical processes. All vital activities, all the things that living bodies do, are brought about by some changes in the arrangement of the stuff that these bodies are made of. The most significant of these changes are chemical reactions between the different kinds of living substance, or protoplasm, that make up the organs and chemical reactions between this protoplasm and the oxygen, water, and foodstuffs received from the outside. These chemical changes taking place within the body are called metabolism. They are accompanied by changes in electrical potential, heat, and movement of parts.

The term "animal behavior" usually refers to the visible movements of the body or its parts; but the invisible chemical, electrical, and other changes are just as truly behavior of the living substance as is our running to catch a train.

But is the body as a whole a machine? Well, it

does some things that other kinds of machines do not. There is no doubt about that. So does every other sort of a machine deliver its own characteristic and unique products different from the others. That is why there are so many patterns of mechanism in the world. That is why people invent new machines and why we are willing to spend money for them. And, as we have seen, new kinds of natural machines are coming in from time to time.

There was a time when there was no life on this planet. At a later time there was life of various sorts, but no live dogs. New species of organisms came in one at a time. Some of the distinctive manufactured products of a particular living machine, say a dog, are bones and flesh and hair and footprints and yelps and, on occasion, pups. No other kind of a machine will deliver these products in dog fashion. But a somewhat different kind of a living machine will deliver rather closely similar products in cat fashion—a little different kind of bones and flesh and hair and footprints, as well as meows and kittens.

Mechanistic biology cannot make good the claim that all animal behavior is carried on according to the laws of inorganic physics and chemistry and nothing more. Its basic idea is that all living phenomena belong to the same natural order as these and are in cause-and-effect relation with them. What a machine does depends on how it is constructed and the situation in which it operates. A locomotive is no good without its track. An airplane does not run on a track or any roadbed because it is built differently. A live bird can do some things that no airplane can do (lay and hatch a clutch of eggs, for instance) be-

cause again it is differently built. Some vital functions are unique and are never seen except in living bodies. They are nevertheless just as truly mechanistic, that is, causally related, as are those of a gyroscope or a wireless telephone, which are also unique.

This is our mechanistic conception of the world. It fits our experience pretty well so far. We find natural mechanisms working with natural forces and delivering natural products. The living mechanisms do not differ in this respect from the dead ones, but they do differ enormously in the details of their action.

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CHAPTER VIII

HOW THE LIVING MACHINERY WORKS

ITS RAW MATERIALS

ALL the raw materials for making a living must come from outside of us, for we have never seen a human being or any other living thing make either its own body or any kind of behavior out of nothing. Both the material and the energy are assimilated from outside sources, just as they are when a mechanic builds and operates a steam engine.

The chief sources are, of course, the food eaten and the air breathed. The internal work of the body consists in finding this precious stuff, transporting it to the parts of the body where it is needed, and then working it over so as to supply this need. In a human body this is a manufacturing enterprise of considerable magnitude, far more diversified and complicated than all the activities of the Union Stock Yards of Chicago.

The energy reserves of the food are partly used for the internal work of the body—to keep the machinery in order—and partly for the external work of our routine work and play.

THE VITAL PROCESS

The vital functions, then, are the output of the living machinery; they are the products manufactured by the working of the bodily mechanisms just

as truly as X-rays are the output of a different mechanism. And the more we learn about the body the more of these mechanisms are brought to light. So we have a mechanistic biology, as well as a mechanistic geology and a celestial mechanics.

Everybody recognizes the differences between inorganic mechanisms, however complicated they may be, and even the simplest living bodies. Some resemblances between them which are often overlooked are brought out most clearly by the analogy between the organism and the river system which has already been mentioned several times. We have borrowed this from Professor Child who says that just as the river is the interaction of water and the channel each in correspondence with the other and always seeking to come to a balanced adjustment or equilibrium, so the organism is the interaction of a living substance of specific hereditary pattern with surrounding things and energies.

Where this activity is going on faster, that part of the body is more alive, just as the river is deepening its channel fastest and doing more of the work of a river where the gradient is steepest. So the apical bud, or growing point, of a pine tree and the head end of a flatworm are more alive than other parts of their bodies. This rate of living can be measured by amount of oxygen consumed, amount of carbon dioxide given off, differences in electrical potential, and by a number of other tests that Child has devised.

Any part of the body that is rapidly growing shows a higher rate of vital activity during the whole growth period and any part which is strongly stimulated will show it temporarily while under the excitation. In

general, the more sensitive parts of the body have a higher rate than the less sensitive parts.

A man is living faster, that is, using up more of the substance of his body and doing more work, while he is fighting off swarms of mosquitoes than he does when sitting quietly in a well-screened house. And the parts of his body that are stimulated by the mosquitoes—by their stings, by the sound of their wings or the sight of their flight—are more alive than they are when no mosquitoes are around. The stings of outrageous fortune, by quickening the vital pulses, may revitalize the body and increase the biological efficiency.

PHYSIOLOGICAL GRADIENTS

The transport of materials within the body is done mainly by the blood-stream, whose chief function is the interchange of commodities of various sorts from one part of the body to another. In addition to this there are lines of transmission of energy, chiefly the nerves, and these are of special interest in this inquiry. These arrangements are in some respects similar to those of a great railway system, whose roadbeds for transportation of passengers and goods are paralleled by lines of electric transmission for the control of the traffic and also for the regulation of the warehouses and factories where the goods are worked up for delivery to the consumer.

But the nerves are not the only transmitters of energy. All protoplasm is irritable, that is, it will release a certain amount of energy when the proper trigger is pulled, or when it is adequately stimulated. This is done by the consumption of some of the living substance; and in most cases it is a process of oxida-

tion comparable with the way the energy of an automobile is derived from the burning of more fuel from the gas tank when the driver "steps on the gas."

All protoplasm, moreover, can transmit this energy through its own substance for a longer or shorter distance. Nerves are more efficient conductors of these streams of vital energy, but nervous conduction does not differ in principle from that of ordinary protoplasm.

The streams of energy that pass out from more active to less active parts are called by Child "physiological gradients." The energy spreads out from the region of more intense vital activity much as electricity flows from a region of high potential to one of lower potential, and it will go by preference along the better conductors.

It must not be forgotten, however, that the physiological gradients are not ordinary electric currents. They go much more slowly and according to different rules. They are known to be combinations of chemical and physical processes, and the rate of transmission is determined partly by the rate of the chemical change. Changes in electrical potential are part of the process and this "action current," which can readily be measured, is usually the most convenient indicator of the gradient.

Professor Child has shown how the vital forces working through these gradients control the growth and behavior of lower animals, and he can even change the behavior and the growth by speeding up or slowing down the rate of living in different places. Normally this is all regulated automatically, but by setting up unusual conditions he can get a small

worm to grow a head where his tail should be, to grow two heads instead of one, or no head at all. The growth of these freaks and monstrosities is seen to be no matter of chance or natural perversity but to go on in ways that are readily controlled as soon as we learn how.

NERVES

Nerve fibers, as just mentioned, are especially good conductors of these vital energies, and they are strung throughout the body like wires in an electrically controlled factory where they will deliver the vital impulse to the apparatus that does the work.

The nerve as we see it in a dissection is a white glistening thread. When examined under the microscope it is seen to be composed of very many finer filaments, the nerve fibers, whose protoplasm is especially well adapted to transmit the excitations from regions of high activity or more rapid rate of living to remote parts. A human nerve may conduct a nervous impulse at the rate of 125 yards a second.

It is certain that there was very complicated behavior before there were nerves. So far as we know this behavior is all unconscious; but no one can be sure of this. A bean plant shows this sort of behavior when it twines around a pole, also a sensitive plant when it shrinks away from a rough touch, and an ameba when it flows away from a pin-prick or flows after its food.

Much of the internal working of our own bodies may go on apart from nervous action or any awareness of it at all. Heart muscle will keep on contracting if entirely separated from any nervous connec-

tions. The pancreas will start secreting its juice as soon as food reaches the intestine, even though all of its nerve fibers are cut away. It is stimulated to action by a substance called "secretin" formed by the intestine and sent to the pancreas through the blood, not through the nerves. This was the first endocrine or internal secretion of a ductless gland ever discovered.

We have a pretty good idea of the way nerves were made out of ordinary protoplasm, but the story is too long to tell here except in briefest outline. In one-celled animals like the ameba where there are no nerves there are physiological gradients of which we have already spoken. These are streams of vital energy that flow out from any part of the protoplasm made active by stimulation. In some other one-celled animals the protoplasm that is most frequently agitated along the lines of these gradients gradually has changed into a denser strand imbedded in the surrounding more fluid substance. These nerve-like strands, which can readily be seen, are better conductors than the rest of the protoplasm, and they carry the excitations from the parts of the body most commonly stimulated to the parts that contract and so effect the responsive movements. This is not a nervous system, but it is the prophecy of one, all inside of a single cell.

The simplest many-celled animals, like sponges, have no nerves at all (Parker), and their vital processes are so loosely bound together that it is hard to tell where the body of one individual ends and another begins. The parts are all so much alike that bath sponges are grown for the market by cutting up

live specimens and planting them in the sea much as seed potatoes are cut up and planted in the ground.

In the next higher animals, polyps, sea anemones, and jellyfishes, some of the body cells are set apart as nerve cells and these are connected up to form a loose network spread throughout the body. We now have division of labor among the cells much as in a human community we have division of labor among the people. Some are farmers, some millers, some bakers, some telegraphers. So in the body the nerve cells are experts in transmission. This puts every part in connection with every other part by tolerably good conductors and makes a jellyfish a much more competent animal than a sponge. The jellyfish has nerves but no brains. Its soft and squashy body lives a free and active life in the open ocean.

BRAINS

In worms the nerve cells are better formed and they are connected up end to end to make definite circuits strung through the body from sense organs to nerve centers and back to the muscles. These circuits, which are the reflex arcs, pass through an adjusting apparatus in a central nervous axis. What the worm does is determined mostly by which ones of these circuits are excited, by what push buttons at the body surface are touched.

Jellyfish lack the central nervous axis and that is why we say that they have no brains; but worms have. To be sure, the worm has not much of a brain, but enough to make it a higher animal as judged by the test which has already been mentioned. Worms can react to what is going on around in more di-

versified ways. In a given situation they can do more kinds of things about it. They are more resourceful than jellyfish.

The life of a jellyfish in the open ocean would seem *to us dreadfully monotonous*, but most kinds of worms live in or on the ground where they have more varied experiences. Instead of having their nerve cells scattered throughout the body in a loose network, most of these cells are bunched in masses called "ganglia," or nerve centers. These are switchboards, more or less complicated, where incoming calls from the sense organs may be shunted to one or another of the outgoing lines depending on what kind of a response is appropriate. The switching system is automatic. There is no little divinity sitting at the switchboard and making the connections more or less accurately and more or less affably according to her mood.

In worms and fish and men and all the animals between we know where most of these switchboards are and what incoming or sensory lines converge into each of them, also what outgoing or motor lines go out from them. We know, accordingly, what kinds of movements can be started by the activation of each nerve center, in a general way.

But several movements can be started from each center, and which one of the several possible movements will be made in any particular situation will depend on many circumstances—on the kind and strength of the sensory stimulation, on the state of nourishment or fatigue of the body as a whole and of the nervous organs concerned in particular, and on many other factors.

The places where these discriminations are made and the conditions under which they are made are rather fully known, but the exact mechanism by which the selection of one or another motor circuit is activated to bring about an avoiding reaction to an injurious stimulation or a seeking reaction to a satisfying object is not yet clear. We know very precisely where the mechanisms are by which a moth flies toward a candle flame and again what apparatus is used to fly away again from the scorching heat. We know some of the internal conditions which must be present to induce an insect to fly toward the light and what changes must be made to cause the same insect at another time to fly away from the same light. But we do not know all of the details of what is going on in the nerve centers when the response to light (the phototropism) is reversed. From the uniformity of the reactions under uniform conditions and from the precision with which measurable changes in the conditions produce reversal of the reaction, we infer that the whole process is radically mechanistic.

It is harder to prove the mechanistic character of more complicated behavior because there are so many ingredients of the situation that we cannot easily locate the decisive factors and get them under experimental control. But considerable progress in this direction has been made even in the case of human behavior, as will appear when we come to the reflexes and the ductless glands.

VITAL CONTROL

The physiological gradients streaming out from regions of higher protoplasmic activity influence sur-

rounding parts and to some degree control their behavior. They do this by means of the streams of vital energy that they send out, much as a magnet controls some of the things going on within its own field.

These high points are, accordingly, sometimes called "centers of dominance" because they dominate or control the functions of the other parts. The more sensitive or excitable parts of the body and especially the sense organs themselves are in this way dominant over the other parts and so control what the muscles, glands, and the rest of our administrative machinery do. This is not figurative language. We know experimentally a great deal about the laws of dominance and subordination of parts by these mechanisms.

Child and others have shown how the physiological gradients and centers of dominance are part of the machinery by which the body adjusts to or corresponds with what is going on outside. Visceral regulation is effected by other centers and gradients of a similar sort. All protoplasm works this way, even that of plants and one-celled animals with neither nerves nor muscles. But animals with nervous systems do it better, and because in the higher forms the nerves run in every direction where especially good conductors are needed, these higher animals can grow bigger and much more complex bodies and they can live much more efficient and diversified lives.

True, the oak tree has a bigger body than a worm, but it cannot wriggle away from danger with it. Its bigness gives it great strength of a passive sort, but without nerves it can do fewer kinds of things with its body than the worm at its root or the squirrel gathering its acorns.

The nerves greatly increase the efficiency of these centers of dominance because they are better conductors and so they enable the centers to control very remote parts more completely and more rapidly, just as an electric generating station can deliver current with less loss to a factory fifty miles away over a copper wire than over an iron wire. A whale would fall apart the way a tapeworm does if it did not have better nerves than the tapeworm so the brain can control what the tail is doing.

The nerve centers of the brain dominate all the others. That is, they exert more or less regulatory control over their activities and over the reflexes that they perform. In man the cerebral cortex dominates all the rest of the brain too. In general, we do what our brains tell us to do. Some of this control is unconscious and some of it is conscious. If our brains are addled and our thoughts confused, say by a little too much gin, they may tell our muscles to do very ridiculous things.

When we say that vital force is transmitted along a gradient or a nerve we do not mean that from the high point of the gradient or the dominant center of the nervous system the energy is poured out that works the rest of the bodily machine the way water from a high reservoir streams down through a flume to operate a water mill or the way an air pump sends compressed air out to work all the drills scattered through a stone quarry. This is an old idea, but we know now that this is not the way the bodily machine works.

Three hundred years ago Descartes elaborated this notion and pictured the soul as living in the

pineal gland in the middle of the brain and sending out streams of vital spirits through the nerve fibers, which he thought were hollow tubes or conduits. Thus the vital spirits activated the muscles by energy derived from a central reservoir in the brain.

It is now clear that neither the soul nor anything else works the body that way. It is more like the way the little daughter of the President of the United States sitting in her father's office in the White House in Washington pressed a button which closed an electric circuit that started all the machinery of a great international exposition of arts and sciences hundreds of miles away. The child did not supply the energy to run those powerful engines. She simply pulled a trigger, so to speak, that released the mechanisms already set up on the exposition grounds. The energy of operation was supplied locally.

So the physiological gradients and nervous circuits transmit the minimal amounts of energy necessary to pull a trigger or activate a relay, to use another electrical analogy, at the far ends of the transmission lines, and there the muscles which are activated in this way supply their own energy to do the work for which they are built.

In the living body these triggers are pulled, not by a little fairy, a Psyche, who flits in and out of the mortal body and activates this or that circuit according to her own caprice. Even the highest centers of nervous control in the brain are law-abiding and orderly in their action, though the mechanisms involved are wonderful and awe-inspiring beyond anything else known.

The centers of dominance, then, are not the reser-

voirs from which is drawn the energy that works the muscles and does the other things that have to be done to keep the body going. These energies are mostly generated locally in the organs that do the work.

It is like Mr. Edison's electrically driven "robot" factory with automatic control of all the machines. The superintendent in his office by pressing this button or that can start one machine and stop another. There is a system of annunciator wires that does the starting and stopping, but the power that runs the machines is derived from another source, or perhaps many sources. Now the nerve centers and the nerve fibers connected with them are like the batteries, pushbuttons, wires, and relays of the annunciator system. Some of them are like transformers that change the strength or rhythm of the currents sent out. These are only analogies, but they are tolerably good ones if it is kept in mind that the nervous impulses are not simple electrical currents but something much more complex and something never found in non-living machines. They are true vital energies. And the "superintendent" is not some *deus ex machina* arbitrarily starting and stopping the works as he likes, something outside the machine. The control is automatic throughout and the mechanisms of control are inherent in the works, not outside.

Some of the higher nervous centers do more than we have so far described. They contain considerable reserves of energy which they are constantly sending out, not to work the muscles directly, but to excite them to a state of steady contraction, to keep them keyed up to action or "in tone."

This tonic action of the brain is very important, and the cerebellum seems to work almost wholly in this way to maintain that steady contraction of the muscles and proper opposing of one against another that we employ in maintaining our balance and postures. The cerebral cortex also is a storehouse or reservoir of "vital reserves," but it works to keep the body alert and "on its toes" in a very different way.

The physiological gradients and centers of dominance are not the only mechanisms of internal control in living bodies, but we have selected them for special emphasis because they are most important and they have been very fully investigated. We shall have something to say shortly about ductless glands and other non-nervous apparatus of regulation.

The brains of higher animals dominate and control the behavior of the entire body, not because the quantity of vital activity (metabolism) is greatest inside of our skulls, but because the energy which is here released is of very special kind. The mechanisms employed are complicated beyond our power even to imagine, and the regulation of behavior is correspondingly precise and intricate. We do not know all the details, but we know enough of them to justify the belief that nervous control is always mechanistic.

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CHAPTER IX

REFLEX

TROPISM, REFLEX, AND HABIT

OUR standard illustration of unconscious nervous action is the reflex, an immediate response to a stimulation, automatic, uniform, unlearned. It is our "natural" inborn behavior. Reflexes are not necessarily unconscious. We may be aware that we do them; but the consciousness is something added to the reflexes, and it requires the action of some additional mechanism of the brain besides that which is able to execute the reflex unconsciously. If a man's back is broken and the spinal cord completely separated from the brain, the separated reflex arcs of the spinal cord can perform kicking movements of the legs, but the man does not know that he is doing it unless he is watching his legs.

Reflex arcs can work without the apparatus of consciousness in the cerebral cortex coming into play. But a conscious or voluntary act cannot be performed without using the reflex arcs. The reflexes come first; the conscious control is added.

We often call almost any kind of an unconscious or automatic act a reflex. But this is inexact. We do not steer motor cars or be polite to our enemies reflexly. These are habits; we had to learn to do it. A reflex is by definition an unlearned reaction, something that grew up with us as part of our original nature.

Reflexes are more primitive than habits or conscious action of any kind. But they are not the starting-point in the study of behavior. A true reflex requires a rather complicated nervous system. Many lowly animals and all plants have no nerves and yet they make very precise reactions to stimulation. These non-nervous responses are more properly called tropisms, or turnings, than reflexes.

An ameba has no nerves, but if pricked with a needle it behaves much as we do, up to a certain point; that is, it pulls itself away from the irritating contact. There is intense activity in the protoplasm at the stimulated point which spreads in every direction. A physiological gradient is set up which permeates the whole body and starts the protoplasm flowing away from the place pricked. The body reacts all over because the whole body is excited by the spread of the irritation. This total reaction we call a tropism, not a true reflex.

THE REFLEX ARC

In worms and all animals higher than these the mechanism of reflex is the reflex arc, or reflex circuit, a chain of two or more nerve cells so arranged that a nervous impulse is carried from a sense organ to a nerve center and then out to some muscle, gland, or other organ of response. The nervous elements are not connected as a network of continuous homogeneous protoplasm, as in jellyfish, but each cell is separated from the related cells of its chain by a barrier termed a synapse. Nerve cells which are separated from one another by such synaptic barriers are called neurons.

THE SYNAPSE

There has been much dispute about the exact structure of the synapse. In some cases there seems to be a very short physical gap between the neurons which the nervous impulse has to cross in order that one of them may excite the next one in the chain to activity. This gap is always filled with fluid which is an electric conductor, an electrolyte, and it may be that only the electric component of the nervous impulse crosses the gap. In most cases the two neurons are in contact but separated by a denser membrane. Some sort of a membrane or other barrier is always present, and it seems to play the decisive part in giving the synaptic junctions their very peculiar properties.

Transmission of a nervous impulse across a synaptic junction is slower and more difficult than along an ordinary nerve fiber; moreover, it can get through in only one direction, that normally taken in the ordinary work of the reflex arc. An ordinary nerve fiber will conduct the nervous impulse in either direction, but the synaptic junction acts as a sort of valve which allows the impulse to get through in only one direction.

Synaptic junctions ordinarily occur only in nerve centers, and they are undoubtedly the most important parts of the nervous mechanism in all the complications of compounding and conditioning reflexes and effecting nervous co-ordinations and adjustments in general. Wherever synaptic junctions occur in a nervous pathway we may be sure that something else besides simple nervous conduction is going on there, some summation of nervous energy, some dispersal or redistribution of the nervous impulses, some

change in their frequency or rhythm or intensity, some provision for the selection of one out of several outgoing pathways, that is, a discriminative reaction or a physiological choice, or some facilitation of one of these pathways more than the others, which is physiological learning.

NERVOUS SYSTEM OF THE EARTHWORM

Worms are the simplest animals that have synaptic junctions in their nervous systems, and their reflex arcs are arranged in a very primitive pattern.

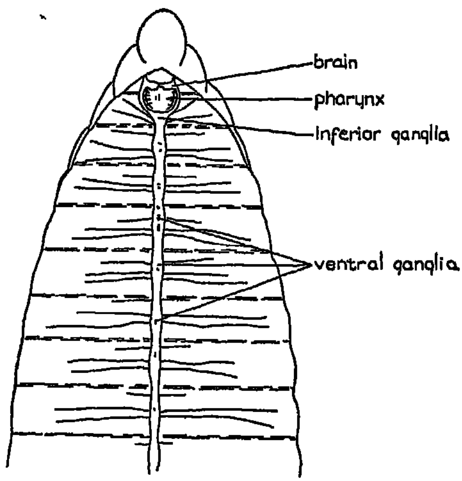

FIG. 1.—The anterior end of an earthworm with all of the body cut away except the central nervous axis and the body wall of the lower side. In each joint of the body three nerves go out on each side. These contain the sensory and motor fibers arranged as illustrated in Fig. 2.

Figure 1 shows the nervous system of the common angleworm as it appears when all the rest of the body except the lower body wall is cut away. The

central nervous axis runs lengthwise through the body with a slight enlargement in each joint, which is a ganglion or center of adjustment. Here the circuits of that joint are all brought together in a sort of switchboard.

If the body is cut across through one of these enlargements, nerve fibers are seen to run from sensory cells in the skin to the ganglion and other fibers go out

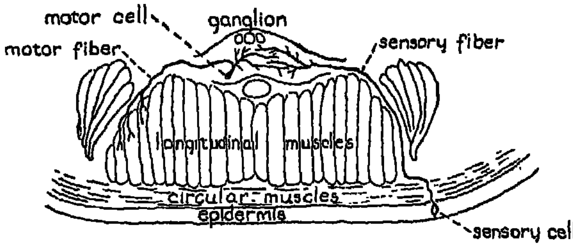

FIG. 2.—Diagram of a cross-section through one of the adjusting ganglia of the earthworm, showing how sensory fibers enter the ganglion and motor fibers leave it to reach the muscles. (Modified from a drawing by Retzius.)

from the ganglion to the muscles, as shown in Figure 2. This is a simple reflex arc containing only two nerve cells. In each joint of the body there are hundreds of such nerve cells, most of which are arranged in reflex arcs connected with the central nervous axis as illustrated.

Running lengthwise through this axis there are other nerve fibers which connect the adjusting centers or local exchanges of the separate ganglia of the body segments much as the different exchanges of a telephone system are connected by trunk lines. This makes it possible for the body to wriggle as a whole in proper wormy fashion instead of each part wrig-

gling separately in disorder. At the head end of the axis is a tiny brain which dominates the rest of the body and sets the directions of its crawly goings and comings. This is an automatic regulator which controls all of the exchanges in the separate joints of the body.

This is the kind of a nervous system that the common angleworm has, and the nervous systems of all animals higher than this are made on a similar general plan. As we go up the animal scale toward man the brain gets progressively bigger and it plays a larger and larger part in the control of what we do.

If earthworms have any consciousness of what they are doing, we have no way of finding it out. If they know anything at all about it, it is evidently a very different kind of consciousness from ours, because worms do not do any of the things that we do with our higher mental functions, such things, I mean, as we do with our cerebral cortex. They do not invent telephones, solve quadratic equations, or tell fairy stories. They have no cerebral cortex at all and so small a brain that you can hardly see it without a magnifying glass. We think with our brains and if worms think with their brains their thoughts must be very microscopic indeed.

There is much that we do not yet know about how the nervous systems of both fishworms and philosophers work. On the other hand, there is a very large number of things that we do know, and it is already plain that we are dealing always with mechanical processes (physical, chemical, electrical, vital) and that it is possible to find out how the machine works if only we try hard enough and intelligently enough.

A HUMAN REFLEX

Let us now take up a simple human reflex. When we jerk the hand away reflexly from a pin-prick on the finger our reaction is as appropriate as that of the ameba, but ordinarily we do not get up and run away all over the way the ameba does. We have nerves and brains and muscles through which a physiological gradient is transmitted and the specific process is kept localized in the parts necessary to give the proper avoiding reaction. Yet the body as a whole may be more or less affected and other things that are going on may be checked or sped up and various ductless glands may be excited to secretion. More adrenalin may be formed, more sugar in the blood, various other visceral actions started, and the whole body may be keyed up and in better tone, all this even though we are quite unconscious that anything at all has happened. Or we may feel the pain and get angry about it, in which case another part of the brain is excited and it acts in connection with the viscera and muscles.

Each reflex action—wink, knee-jerk, and the like—has a nerve center somewhere which automatically sets off this particular response whenever the proper button is pressed, or in more technical language whenever an adequate stimulus is applied.

In strictly reflex activity the nervous system works unconsciously very much like an automatic telephone exchange. A mosquito bites my face. That presses a button of a transmitter which sends the message to the brain. Here it is received, tagged as from the appropriate sending station, sent down to the spinal cord through several relays, and out to the arm muscles which slap off the offending insect. If the shoul-

der is bitten a similar message comes in, but from a different sending station. Again the hand is brought up to slap; and it slaps the right place, not the face this time. It is all perfectly automatic. I may do it when I am asleep.

The nervous connections involved in these and countless other reflex acts are well known. It is this kind of knowledge that enables the physician to diagnose the place that is out of order in nervous diseases, and often to correct the trouble and cure the patient. If some particular reflexes, like those from one side of the face, do not take place in normal ways and everything else seems all right, it is evident that this circuit is interrupted somewhere, and the doctor can usually tell where the trouble is and what it is. Sometimes he can correct it by splicing another nerve into the place or in some other way.

The amount of detail that is known about the structure and connections of the reflex arcs is enormously great, more than most physicians even appreciate. This organization is much more complicated than you would get if all the telegraph and telephone systems of the world were connected up into a single big system.

Figure 3 illustrates the conventional diagram of a simple reflex such as jerking the hand away from a pin-prick. A sensory and a motor nerve of the left side of the body are represented each by a single nerve cell, or neuron, with its related nerve fiber. In reality there are hundreds of such nerve cells and fibers in each of these nerves.

A single nerve fiber of a sensory nerve passes from the skin of the finger through a spinal ganglion into

the spinal cord. This fiber is the outgrowth from the nerve cell body situated in the ganglion. This cell body and the fiber connected with it comprise a single neuron, a sensory neuron in this case.

This neuron makes connection within the gray matter of the spinal cord with a motor neuron whose cell body lies within this gray matter and whose nerve

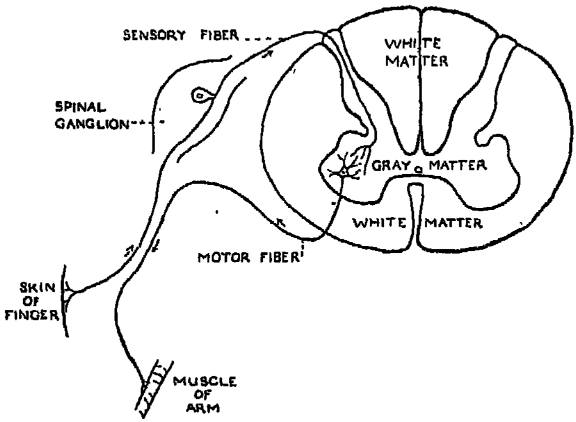

FIG. 3.—Diagram of a cross-section of the spinal cord and its nerves, illustrating a simple reflex arc. Two nerve cells, or neurons, are involved in this reflex, a sensory and a motor.

fiber passes out to end in a muscle of the arm. The connection between the two neurons is the synapse.

This is a two-neuron reflex arc. In the diagram the numerous collateral connections of these neurons are omitted. This reflex arc is in reality connected with many others in the same region and in remote parts by a complicated system of nervous pathways which are not shown in the figure.

This sort of a simplified diagram is a convenient

introduction to the study of reflex arcs; but it must not for a moment be lost sight of that it is not a true picture of the actual structure. This arc is interconnected with countless others by a web of nerve cells and nerve fibers of great complexity. It never acts alone, but always as a part of this larger system of interwoven nerve cells and fibers. Some of these circuits appear to be better conductors of the nervous impulse than others, so that in the typical reflex response to some specific stimulation the same thing is likely to happen every time. The reflex response to this stimulus is uniform or standardized.

But some small and unobserved change in the central or peripheral part of the apparatus resulting, say, from fatigue, indigestion, or a disturbance of the balance of the internal secretions may change the conductivity of some part of the system and so divert the nervous excitation from the usual standard pathway to some other way. Then something else happens, some reaction follows which is not the typical or standard reflex response to this stimulus. This is why it is so easy to modify or condition reflexes, a thing which could not happen if every reflex arc were separate from all the others and as completely insulated from them as are the wires of the separate electric circuits in a properly wired house or factory.

The knee-jerk is a typical reflex much used in medical practice. The foot is lifted off the floor, the tendon of the knee-cap is tapped, and the foot is jerked forward. It is done by a mechanism of the spinal nerves and spinal cord similar to the one shown in the simplified diagram (Fig. 3). It is done automatically and unconsciously, one does not learn it,

and it is not improved by practice. Dr. Raymond Dodge put himself through a course of training and got 1,032 records of his knee-jerk. There was no improvement or facilitation of the reaction by this prolonged practice. It is one of the simplest reflexes, yet it is a very complicated thing and various people do it differently.

The knee-jerk can be performed by a spinal cord separated from the brain as a strictly local reaction; but ordinarily the nervous pathways leading to the brain are excited too and in that case one may be conscious of it. Because these pathways are ordinarily used as well as the local reflex arc, the reflex can be modified or conditioned by Pavlov's method to be described shortly.

DEVELOPMENT OF REFLEXES

The earliest stages in the development of reflexes have been studied by Coghill, who finds that mass-movements of the body as a whole come first, that is, total reactions of all the muscles whose neuro-muscular development has advanced far enough to make it possible for them to respond to stimulation. As the particular organs of the body gradually mature—arms and fingers and toes—their more special reflex movements are at first made only as parts of the general total reaction of the whole body and later they are emancipated so as to be able to go on as local reflexes. The local reflex, accordingly, emerges from the mass-reflex and it always retains a significance for the body as a whole, and an anatomical connection by collateral nervous pathways with the body as a

whole. In terms of the *Gestalt* psychology, it is always a local configuration on a much wider background, which is the whole organization of the animal in relation to its environment, and it has no significance except within that total situation. It is a function of the body as a whole, not of a particular chain of nerve cells and muscle fibers.

In the development of the reflexes used in walking the local reflex "is intricately involved from the very beginning with the behavior pattern of the entire animal" and "there is the individuation of parts within the total pattern and not integration of essentially or primarily independent units." Dr. Coghill gives a very exact account of this process and of the anatomical mechanisms employed at each stage of the emancipation of the local reflex arcs from subordination to mass-reflexes.

Reflexes and reflex arcs are real things, and if a doctor suspects any nervous disease he generally tests the reflexes of his patient the first thing. But these reflexes are not *simple*, nor are they the primary elements or units out of which behavior has been built up, as so many people seem to think. The body behaves as a whole while it is so young that no separate reflexes have appeared. The local reflexes come later and at first they can be executed only in connection with movements of the whole body. Later the local reflex can work without the general bodily movement, yet even the finished reflex arc works as part of the whole body and not as a separate nervous organ as well insulated as the electric circuit of your doorbell. That is why reflexes are so variable and why their

variations can tell the physician so much about the general condition of the nervous systems of sick people.

The apparent simplicity of the reflexes is illusory. In fact, the "simple reflex" of the textbook descriptions is a pure abstraction. Nobody ever saw one in a human body. The actual events even of a wink or a knee-jerk are far more complex than our conventional diagrams indicate.

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CHAPTER X

CONDITIONED REFLEXES

MECHANISTIC LEARNING

A BRIGHT light flashes in the eye and the pupil contracts. A tap on the tendon of the knee and the foot is jerked forward. For each of these and countless other reflexes there is a nerve center which regulates the act so that it generally goes off quite regularly and uniformly. This is just as mechanical a process as that of an automatic telephone which rings up a particular subscriber every time the appropriate numbers are signaled at the transmitting instrument.

But, as we have seen, this is not all that takes place when a reflex arc is set a-going. In a good automatic telephone system every circuit is so well insulated from every other circuit that there is no leakage of current from one circuit to another. The business deal that I am negotiating over my telephone cannot be overheard by my competitor when he listens through his telephone. Of course, there are some kinds of party lines where this can take place, and the brain is full of such party lines.

The reflex circuits in general are not so well insulated from one another as the electric circuits in any telephone system, even rural party lines where everybody runs to the 'phone every time any other subscriber's call is rung. If they were our nervous systems could not learn as they do.

An automatic telephone exchange will not learn to give you a particular number any better if you call it up a thousand times in succession, and it will never learn to give you forthwith the butcher after you have called up the grocer in the usual way, even though you have called up these two shops in this order a thousand times.

This is just the sort of thing, however, that reflex circuits may do—not always, as we saw in the case of the knee-jerk, but sometimes when interconnected in appropriate ways. They may learn by repetition and they may be modified by practice. Now, of course, this modification by use is not an exclusive privilege of living things. Any complicated machine is better after it has worn off the stiffness of new bearings and gears. The motor car is likely to run more smoothly the five-hundredth mile than it did the first mile, and Kipling's "Ship That Found Itself" was a better ship after its first transatlantic run.

But machines can modify their behavior by use in more interesting ways than this. An engineer, Mr. S. Bent Russell, has designed an engine which performs some tricks that in a living body we would call "associative memory." In this engine, as in a nervous system, changes are effected in the operation of the interior mechanism as a result of experience, or rather of the operation of the mechanism,

so that with the same signals as before the responses have changed and *vice versa* we find the same responses when the signals have changed. We have a mechanism that can be trained, that can acquire habits, that will move either forward or back at a given signal according to experience, that will make one, two or three responses to a given signal according to experience.

Mr. Russell's engine starts and works in the way determined by its own structure, the same as our reflexes do. It also changes its way of working so that after a while it is doing something very different, just as a dog's reflexes may be changed, quite unintentionally on his part, by his own experience. This engine possesses associative memory according to Loeb's definition: "If an animal can be trained, it can learn, it possesses associative memory." We have a much more striking illustration of this automatic modifiability of inorganic things in the phenomena of autocatalysis (see G. N. Lewis, *The Anatomy of Science*, p. 181, and A. P. Mathews, *Physiological Chemistry*, pp. 67–69).

ASSOCIATIVE MEMORY

The practice that makes perfect in a living body does this, or something like it, and it goes much further than this.

The simpler forms of learning by experience were called by the earlier students of animal behavior "associative memory." A classical example is the experiment of Möbius made in 1873 and since repeated by Triplett and others. He put a pike in one end of a tank which was divided in the middle by a transparent glass partition. In the other end of the tank he put some minnows which are the natural food of the pike. The big fish, being hungry and seeing the minnows, reflexly darted after them and then bumped his nose on the glass partition. After many bumps he learned that this did not pay; at any rate, he stopped doing it. Then the glass partition was removed and the pike swam freely among the minnows. He was as hungry as ever, but having learned that every attack

on those minnows meant a bump, he remembered it and let them play all around him without disturbing them in the least.

This simple kind of learning with its ridiculously impractical outcome is, so far as we can tell, not fundamentally different from the learning feat performed by Bent Russell's engine. Loeb, as just mentioned, used this kind of associative memory as a test of consciousness in animals. "Consciousness is only a metaphysical term for phenomena which are determined by associative memory." But if this proves that Möbius' pike was conscious, it also proves that Bent Russell's engine was conscious. It seems to prove too much. Really it proves nothing. I see no way to find out whether the engine or the fish was conscious by this sort of experimentation. Both are certainly machines—whether conscious machines or not, who knows? It is safer to follow the ancient rule of parsimony and not invoke the higher law of consciousness when the lower law of the unconscious will serve.

PAVLOV'S DOGS

This kind of associative memory is called a "conditioned reflex." Other cases of conditioning work in a great variety of ways. The classical example is Pavlov's dogs. A dog naturally salivates when fed, just as we do. He does not naturally secrete saliva in response to ringing a bell because under natural conditions dogs are not called to their meals by dinner bells. But if the bell is rung every time he is fed, he will salivate after a while at the ringing of the bell even if no food is given or is anywhere about. He has "conditioned" his natural reflex so that the flow of saliva comes under the new or learned conditions. A com-

prehensive account of Pavlov's experiments has recently been translated into English.

MECHANISMS OF CONDITIONING

Our knowledge of the mechanisms employed in this sort of learning by conditioning of reflexes is

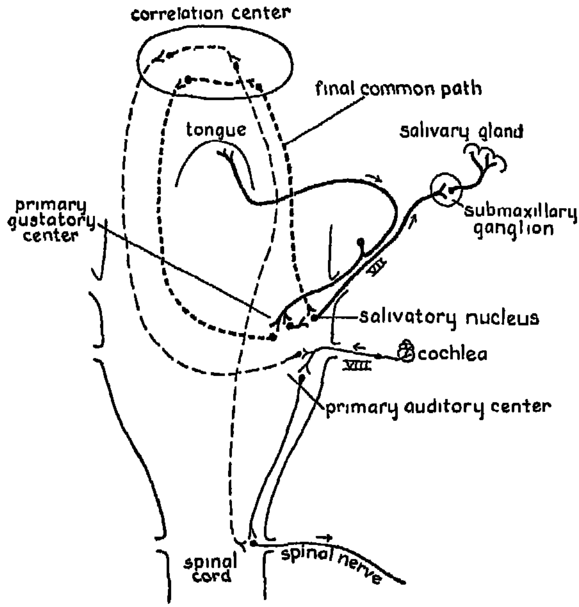

FIG. 4.—Diagram of the mechanism of a conditioned reflex. (From Herrick's *Brains of Rats and Men*, University of Chicago Press, 1926.)

tolerably complete and satisfactory up to a certain point. We know the sensory and motor apparatus employed and the nervous pathways traversed with sufficient accuracy.

Figure 4 is a diagram of this apparatus in a typical instance of conditioning by Pavlov's method. In this

case a dog learns to secrete more saliva than he ordinarily does (and a definite measurable quantity more) when a bell is rung, a thing that he does not do "naturally," for this is not a part of his inborn reflex behavior pattern.

Ordinary unconditioned secretion of saliva is brought about by stimulating the organ of taste or the organ of smell by food. The reflex arc for taste is shown by heavy continuous lines from tongue to salivary gland. Another unconditioned reflex is the turning of the head in response to ringing a bell. Its arc is drawn in lighter continuous lines from the ear to the muscles of the neck through a spinal nerve. There is no direct connection between the reflex arcs of salivary secretion and turning the head; but there is an indirect connection (shown by dotted lines) between them through the correlation center, in this case in the thalamus or cerebral cortex.

Now if the bell is rung every time the dog is fed, the indirect connections are simultaneously excited and the correlation center receives nervous impulses from both arcs at once. The two experiences come to be associated, and after a number of such experiences the dog will salivate when the bell is rung even if no food is given. The auditory reflex has become conditioned so that it now gives the response originally given by the taste reflex instead of its own response. In other words, the dog has learned to salivate when the bell rings. He cannot do this if the higher association center is disconnected from the lower reflex arcs, as may be done by a surgical operation.

This much of the story is clear. Now if you ask for the details of just what is going on in the nervous

centers of correlation during the process of conditioning or learning, nobody can give a satisfactory answer. This remains to be found out. There are many theories, but we need not go into these. This field is now being explored very carefully.

LEARNING UNCONSCIOUSLY AND CONSCIOUSLY

In the lower animals, as in insects, most of the behavior is in rigid reflex patterns with little conditioning by personal experience. They can learn only a few things and that with difficulty. They can do no better with the brains they have. These brains have very small correlation centers and the reflexes are simply conditioned.

In higher animals a larger proportion of the behavior is conditioned, that is, personally learned. Parallel with this the size and complexity of the brain increases from lower to higher animals. The correlation centers, in particular, are progressively enlarged. In man so little of our ordinary behavior is unconditioned that the human infant at birth is far more helpless than are the babies of other mammals, and most of our adult behavior is highly modifiable.

This is because the human cerebral cortex is bigger and more of our learning is of the cortical or intelligently directed kind. Parallel with this enlargement of consciously directed learning power, the more primitive physiological learning loses some of its independence and becomes more subordinate to the dominant conscious direction and control. All conscious behavior is individually learned, that is, in so far as it employs our inborn reflexes it uses them after they have been conditioned by personal experience.

Roy Chapman Andrews in a motor car paced a Mongolian antelope ten days old and says the baby ran four miles in ten minutes. Another time he saw a colt of the wild ass less than a day old run more than a mile at a speed of twenty miles an hour. A newborn colt of our farmyards cannot do as well as that, but it is pretty steady on its feet and can trot along with its mother before it is a day old. It is about a year before a human baby can do that, and he never becomes as good at it as the colt is. In fact, before he is many years old that is the last thing that he wants to do.

Our human reflexes mature very slowly and they are almost from the start woven into learned patterns of behavior. They appear to be held back, not allowed to crystallize into rigid molds, too early. This keeps them pliable so that learning is easier.

We shall take up learning presently, and we shall find that all learning is a growth—a growth in bodily structure. It is not always a growth in knowledge, for there are some kinds of learning that go on quite unconsciously, by linking up reflexes in new ways, that is, by conditioning the reflexes. The nervous mechanisms of all the more complex forms of conditioning and learning are in a special part of the brain, the cerebral cortex.

The baby's cerebral cortex is immature at birth; and for several weeks after birth it is too busy growing in size and complexity of internal texture to take any active part in learning. So the newborn baby's reflexes are fewer and less perfectly knit into effective working patterns of behavior than those of most other animals are. He is far more helpless and his infancy is prolonged to give time for his cortex to

catch up with the rest of his growth and take charge of it. As fast as the apparatus of the separate reflexes matures and grows up to workable form it is woven together into learned patterns and the further growth is shaped by experience, by conscious learning.

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CHAPTER XI

BRAINS

SIMPLE BRAINS

WORMS and clams have made only small beginnings toward the development of brains. They have numerous minute centers of adjustment, the ganglia, which are widely scattered throughout the body conveniently placed near the organs whose activities are to be regulated. The ganglia which are in the head near the principal sense organs are obviously dominant over the others, and these are all the brains these lowly creatures have, as we see in the earthworm shown in Figure 1. But some animals of this grade have no heads and no brains at all, only the scattered ganglia.

As we go up the scale of animal life from ineffectual crawling things toward the higher and more enterprising citizens of the animal kingdom—insects, fishes, birds, monkeys, and so on—the increase in the size and complexity of the brain gives a rough indicator of improvement in the range and efficiency of their behavior, their competence in adjusting their lives to the hazards of an unfriendly world. So accurately do the sizes and forms of different brains reflect the sensory and motor capabilities of their owners that the neurologist with a collection of brains of unknown animals before him can give a tolerably accurate account of the habits of each of them, incomplete, of course, but reliable as far as it goes.

Some years ago a geologist brought to my desk a tiny fossil less than a half-inch long. It proved to be the brain of a little fish found in carboniferous rock of the Coal Measures, so we know that the animal that used that brain has been dead at least fifteen million years. This tiny relic of the age when primeval jungles were laying down our present coal seams is so different from the brain of any living fish that it cannot be classified with any of them.

Very little of the rest of the body was preserved, and yet we can say very confidently that its possessor had very large eyes and good sense of smell, but not so large olfactory organs as in some modern fishes, that the sense of taste was much better developed than in most other fishes, but not so well as that of a carp, and that it was not a strong and active swimmer. The sense organs of the lateral line system (peculiar to fishes) were moderately well developed. This we know, though none of the fish is preserved except the brain. We could tell much more about its habits if the internal structure were as well preserved as the external form. In a similar way the brains of the higher animals vary in size and shape and texture in correlation with differences in their habits, their adaptability, resourcefulness, and learning power.

THE HUMAN BRAIN

Turning now to the human body, we see that our own nervous systems consist of a central axis, the brain and spinal cord, and running out from these the nervous strands that connect these centers with outlying parts—sense organs, muscles, viscera. There are central directive and administrative offices in the

nervous axis, very complicated in organization, and in intimate connection with these central offices there are numberless branch offices, subsidiaries, and agencies scattered all over the body. The peripheral nerves and the central nervous pathways (tracts) are the lines of communication which bind all these together as a single working system.

Interwoven with the viscera, and indeed with most other parts of the body, are the sympathetic nerves and their ganglion cells. This delicate web of nervous filaments, fine as gossamer, is threaded through all of the active organs of the body—under the skin, enwrapping glands and blood vessels, permeating all the muscles, and woven into the tissue of the organs of digestion. Much of the work of the viscera is regulated locally by these outlying substations of the nervous apparatus of control of behavior. Most of the routine of digestion, for instance, is automatically adjusted by the web of sympathetic nerves which is inclosed within the walls of the stomach and intestine.

Numerous communicating nerves connect the outlying sympathetic system with the central nervous axis, and within the spinal cord and brain are switchboards and control works by means of which all visceral activities are regulated and kept working together in harmonious co-operation and proper balance. The whole apparatus of nervous control of visceral activities, central and peripheral, is included in what is here called the visceral nervous system.

The part of the nervous system contained within the skull is the brain, illustrated in Figure 5, and the part which is inclosed by the bones of the spinal col-

umn down the back is the spinal cord. Only a small part of the central nervous axis (brain and spinal cord) is concerned directly with visceral control through the sympathetic nerves. The rest, and by far the larger part, controls the general body muscles, or so-called voluntary muscles. Because it regulates the behavior of the body as a whole (soma) in its

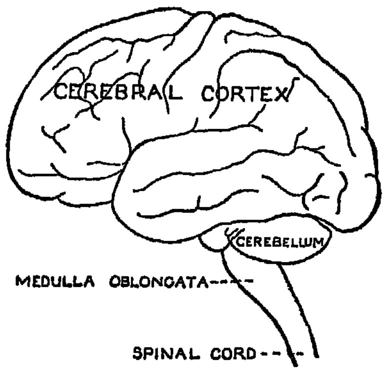

FIG. 5.—The human brain seen from the left side, about one-third natural size.

external adjustments, it and the related peripheral nerves may be called the somatic nervous system.

The cerebral cortex is the dominant part of this system. It is an overlord that governs the somatic nervous system and through it our adjustments to the environment and the people in it. This is a direct and authoritative control. The cortex may also regulate visceral reactions, but always by an indirect route through the visceral nervous centers in the underlying parts of the brain; and the authority of the cortex over our visceral behavior, our digestion,

blushing, and sexual impulses, for instance, is relatively weak and precarious. This accounts for the difficulty we so often experience in keeping emotional outbursts in hand.

The substance of the brain and other massive nervous organs is composed partly of white matter and partly of gray matter, as can readily be seen by cutting it open almost anywhere. The white matter is made up chiefly of nerve fibers, mere conductors. The gray matter comprises the nervous centers with which these fibers are connected. It contains the nerve cells and also very elaborate switchboard devices for shunting the nervous currents about and finally discharging them outward to the muscles or other organs of response. The amount of gray matter in different brains is popularly (and correctly) taken as a rough index of the relative efficiency of those brains in the control of behavior.

OLD BRAIN AND NEW BRAIN

The brain may be divided for our purpose into two parts, each of which in man comprises approximately half the total weight of the whole. The older part is the so-called brain-stem and the cerebellum; the newer part is the cerebral cortex which makes up most of the two cerebral hemispheres borne on the stem at the top and filling the top of the head. If the cerebral cortex and cerebellum are cut away the appearance of the brain-stem is seen in Figure 6.

CEREBRAL CORTEX

The cortex, or new brain, is the wrinkled and convoluted gray layer, about an eighth of an inch thick,

that covers the surface of the cerebral hemispheres which fill the massive dome of the skull. It is made up of nerve cells and innumerable fine, much-branched, and intertwined nerve fibers. It is the place where all kinds of nervous impulses from all over the body are brought together and recombined into outgoing nerv-

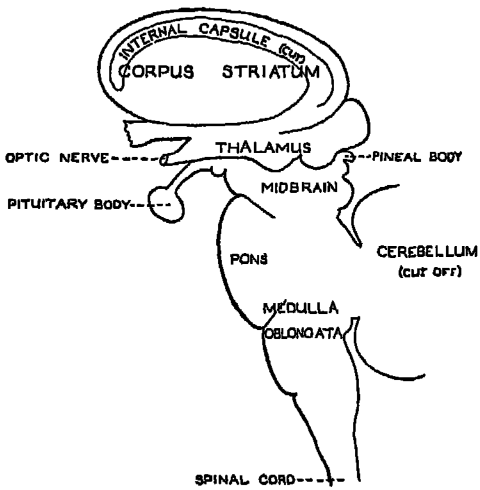

Fig. 6.—The brain-stem with cerebral cortex and cerebellum cut off, seen from the left side. The internal capsule contains fibers between the thalamus and the cerebral cortex.

ous currents which activate the muscles to do what they are told to do. The structure of the cortex is so very complicated that it cannot be adequately shown in pictures, even if we use a great many of them.

The lowest animals have no well-developed cerebral cortex, not even the lower backboned animals like fishes. It is simply but very clearly developed in

reptiles, and from here on it increases in size and complexity until in man it makes up nearly half our brains. This cortex, or "pallium," is so big that it grows over and around most of the rest of the brain, wrapping about it like a cloak or mantle (*pallium* means mantle).

It is estimated that the human cerebral cortex contains 9,200 million nerve cells, and these are interconnected through the white matter in so complicated a pattern that the total number of different ways in which they may be linked in chains of physiologically co-operating neurons is so large a number that it seems futile to try to express it in figures. Some reflections upon the possible functional meaning of this arrangement will be found in the first chapter of my *Brains of Rats and Men*.

It is sometimes supposed that all activities of the cerebral cortex are conscious and that our subcortical activities are all unconscious. But this is not the case. It is true that the larger part of our mentality depends on the cortex and normal conscious life is impossible unless this apparatus is in good working order. But certainly there is much cortical activity that is wholly unconscious, and our simplest emotional experiences and perhaps some crude forms of sensation are carried on in the brain-stem.

The cerebral cortex does radically different things from the stem portion of the brain. It is the final arbiter of our conduct and it also attends to much of the routine drudgery of life, especially the learned drudgery, the fixed habits of life, that we have acquired.

BRAIN-STEM

The brain-stem (Fig. 6), or old brain, is very complicated too, even in primitive sorts of animals like fishes which have no well-formed cerebral cortex at all. It takes care of reflex movements of the head, and those of the trunk and limbs as well so far as these are not regulated locally in the spinal cord. The simpler forms of conditioning of reflexes, or biological learning, are also done here, especially in the thalamus; but most of the conditioning and consciously directed learning is cortical.

The visceral control works of the spinal cord and brain include simple reflex arcs like those that regulate secretion of saliva while food is being chewed and attend to the details of swallowing after mastication is complete. There are also higher regulatory centers in the very middle of the brain (thalamus, Fig. 6) where the separate visceral processes are reported and kept in proper co-ordination and balance, so that chewing and tasting and swallowing and breathing and bawling out the cook for burning the toast will not work at cross-purposes. The general regulation of body temperature is attended to here, and also the local activities of the ductless glands or endocrines are played off one against the other with mutual reinforcement or reciprocal restraint.

These higher visceral centers are not in the cerebral cortex, though they are under some cortical control. Visceral functions go on for the most part unconsciously; we do them better the less we attend to them; in fact, while we are in good health we should not even know of their existence. But we are aware of some of them.

THALAMUS

The thalamus is a very complicated region, and one of its duties, it is now believed, is the conscious recognition of visceral reactions, our simple pains, pleasures, and emotions. Uncomplicated and unanalyzed emotion is probably a thalamic function. There are no cortical centers known for any of the elementary emotions or satisfactions, and some authorities say that the experience of simple pain is not a cortical function.

But the thalamus is intimately connected with the cerebral cortex by very complex systems of nerve fibers which run to and fro between them. They run in the internal capsule shown cut off in Figure 6. Whenever elementary emotions, that is, simple affective experience in psychological terms, are complicated by interpretations, are elaborated through association with other kinds of experience into sentiments, sympathies, aversions, jealousies, and the like, or are deliberately joined with impulse in voluntary action, then thalamus and cortex are working in partnership. The thalamus supplies the emotional coloring, the agreeable or disagreeable quality, and the simple impulsive drives; the cortex supplies the intelligent guidance and rational control.

The thalamus, then, discharges two ways, downward toward the motor centers and upward toward the cerebral cortex. The former regulates and reinforces our elementary visceral reactions and is one of the most primitive functions of the brain. The latter links these reactions and the accompanying emotions with the higher centers of intelligent control and keeps them in hand in the more restrained life demanded by good society.

THE DOCTRINE OF LEVELS

The nerve centers of the brain, spinal cord, and sympathetic ganglia scattered throughout the body are arranged in "levels," or hierarchies, each higher level controlling those below it.

These levels are ranked in order of their relative dominance something like the way our political units are organized. The village is subordinate to the town or county; the county to the state; and the state to the federal government. Each of these levels does a large amount of business with its own local organization without supervision from any higher office. There is a certain degree of local autonomy, and progressively more capacity for local control as the series of levels is ascended. The cerebral cortex at the top of the nervous axis is the center of highest dominance, and it exerts more or less control over all the lower centers and through these over everything that the body does.

SPONTANEOUS ACTION OF THE BRAIN

The brain by itself and apart from the rest of the body initiates nothing. None of its activities is "spontaneous" in the sense of being self-starting. The self-starter of a Ford car will not start the car unless somebody steps on it; so the action of the brain has to be started by something. This is true of the smallest and most primitive brains that we know anything about and also of the biggest.

The simplest brains known are found in some of the smaller worms. These are even more primitive than the minute brain of the earthworm shown in Figure 1. These little flatworms are swimming and

crawling around much of the time. If they are decapitated these so-called "spontaneous movements" cease; the brain ordinarily starts them, but the brain does not start them of its own initiative.

A. R. Moore has shown that in decapitated worms the mechanisms of the locomotor movements are still present and will give normal movements if properly stimulated, but they will not start unless directly and rather strongly stimulated. There is no so-called spontaneous movement. He says:

> The neuro-muscular mechanism necessary for spontaneous movement and swimming is complete in the body apart from the brain. Normally this mechanism is set in motion by sensory stimuli arriving by way of the brain. The latter is a region of low threshold and acts as an amplifier by sending the impulses into a great number of channels.

The brain centers are knit in with bodily processes, including those of lower nervous centers, as going concerns. They will act when excited from these lower centers to facilitate and diversify the standardized behavior patterns, but they do not act "of themselves" and apart from what is going on in outlying parts.

When the brain is there and connected up with the lower centers smaller stimuli are effective to start movement than when the brain is cut out of the circuit. This is just as true of the human brain as it is of the flatworm's brain; but in our brains the "amplifier" has been enormously enlarged and complicated. The cerebral cortex is a vast storehouse of latent reserves of potential kept on call in the chemically unstable protoplasm of its 9,200 million nerve cells. It

also contains the "living residues of past experience," the structural alterations which form the organic basis of our memories of former events and our reactions to them. These too are on call and can be reactivated on demand.

The way the cortex actually works as an amplifier of very feeble sensory stimulation may be seen in the case of a man who is drifting at sea in a catboat after dark in a fog. He has no compass and is "all at sea" about his position and course. He knows he is drifting, but whether landward or seaward he has no means of finding out. While straining eyes and ears for the faintest directive sign, the fog breaks momentarily and he glimpses a point of faint red light on the port bow. The Barnacle Bay light! He notes its direction with reference to wind and tide-rip and takes his course down the wind in serene confidence that it will take him directly to his haven.

A twinkle of light, the smallest stimulus to which his retina is sensitive, instantly transforms the slump of dejection into hilarious elation; with a shout of joy he leaps to halyard and tiller and that flash of perception may guide his course for hours to come. He knows his coast and its beacons. The one glimpse of a familiar marker was enough to give him his position and release all his latent reserves of physical energy and nautical skill. Without that background of experience, retained somehow in available form in the set-up of his cortical machinery, the point of red would have meant nothing to him, the "amplifier" would not have been activated, and no reserves would have been drawn upon to transform dejection into hope and animation.

The whole cortical apparatus is wound up and set on a trigger so that its latent reserves of motive power and memory patterns may be released by the slightest impulse set in motion by some external event or some change in the interior of the body. But this impulse must be "adequate" physiologically, that is, it must be attuned to the cortical set-up which is to be activated. Such a red light seen in the zenith, say from an airplane, would give as strong a stimulus, but the "amplifier" would not respond. In psychological terms, the perception would not be apperceived.

Even the most apparently spontaneous of our voluntary impulses and imaginative fantasies do not come uncaused. Some event outside (or perhaps inside) the cerebral cortex pulls a trigger which releases a mechanism already so set up or organized that its operation goes off according to the pattern determined by the set-up of the apparatus. The result may be to start some apparently spontaneous bodily movement or some mental process of thinking, reverie, or inspiration. The feeling of spontaneity is real; the process is a genuine determiner of behavior; it is not uncaused.

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CHAPTER XII

BRAINS AND VISCERA

WORKING WITH BRAINS AND WITHOUT THEM

SOME years ago I stood at Dr. Cannon's side in the physiological laboratory at Harvard University watching one of his experiments on the process of digestion. A short time before, a cat had been fed some milk containing inert bismuth powder to make it opaque to the X-ray. Now she was lightly tied down upon a table and the movements of the intestine containing the food in course of digestion could be easily seen in the fluoroscope. The cat had been there before and was used to the procedure. She seemed perfectly comfortable and contented and purred when Dr. Cannon stroked her head. Digestion was going on with normally rhythmic movements of the intestinal muscles, every detail of which was clearly visible. She appeared to be experiencing the comfortable feeling of satiety just as you and I do after a good meal. Now a sudden sharp pinch of the cat's tail. She bristled with anger as every proper cat does when subjected to such an indignity. As we watched the fluoroscope every digestive movement stopped instantly. A curb was put upon these visceral muscles and others were activated instead, those more appropriate to the new situation. Digestion does not go on during snarling and scratching. Ten minutes later, after puss had been petted and com-

forted up a little, digestion proceeded just as if nothing had happened.

Our taboo of disagreeable topics at table and our fondness for good after-dinner stories are based on sound physiology, though perhaps we did not know this when these habits were built up.

The ordinary visceral routine of digestion and so on goes on very well without any help from the brain, but the digestive process can be completely demoralized and the organs of digestion wrecked beyond repair by meddlesome interference from the brain, especially by pain and worry. The chief advantage of good company and good stories at the table is the distraction of attention from other things that might interfere with the routine of digestion which is best carried on locally by the organs concerned.

There is some nervous regulation of these visceral actions, partly by outlying sympathetic nerves and ganglia and partly from the brain. This last may be conscious or we may be quite unaware of it, and very different mechanisms are employed in the two cases. If we are at all conscious of this visceral behavior we have an emotion and in this case we can put our minds to it and may keep our visceral reactions and our emotional outbursts in hand. This last is not a function of viscera or the visceral nervous system. It is done by the cerebral cortex.

THE DUCTLESS GLANDS

The internal control works of our bodily machines are of two very unlike sorts. First, there is the nervous system already described and, second, there are chemical regulators that work in a very different way.

Scattered throughout the body are numerous glands which have no ducts or outlets. They secrete specific chemical substances which are passed directly into the blood-stream and so are carried everywhere. These glands in the aggregate form the endocrine system and their secretions are chemical messengers, some of which are called hormones.

These hormones are chemical regulators or adjusters, sharing this work with the sympathetic nervous system. The nerves transmit only energy, but the hormones are secreted materials that have to be transported by the blood. Each part of the body is sensitive to certain ones of these chemicals and its action is accelerated or slowed down in proportion to the amount of its own specific hormone present in the blood at the time. By this means all parts of the body are kept in proper equilibrium or working balance and one part or another is sped up as the exigencies of life require. The chemical adjusters are found in all animals and all plants though not all of them are called hormones.

The case of the internal secretions of the human body is a bit like that of a man who lives in a big apartment building and wants to know whether his crony, Dulce Fumerole, who lives downstairs, has come in. Dulce has no telephone. Presently he gets the familiar odor of Dulce's briar pipe. He knows he is home and he goes down for a chat. The other occupants of the building who do not know Dulce pay no attention to his pipe. So the hormones spread throughout the body fluids and quicken to activity those particular reacting mechanisms that are in sensitive attunement with them and no others. Now if

Dulce had a telephone, his upstairs neighbor upon smelling the pipe might reach for his own 'phone and call down to make a dinner appointment with him at the club. In a similar way our nervous systems supplement our endocrines and transact a great deal of our internal domestic business in much more precise way than endocrines alone can do it.

The chemical adjusters always work unconsciously. Each of the ductless glands produces one or more specific hormones. The thyroid in the neck if enlarged makes a goitre. Normally it secretes a substance containing iodine (iodothyrin) which assists in the regulation of the nutrition of the body. The thymus, below the neck, is very large in infancy and disappears in the adult. It assists in the regulation of growth. The suprarenal gland above the kidney secretes adrenalin or epinephrin which raises blood pressure, increases the amount of sugar in the blood, and thus indirectly increases the tone of the body muscles.

Adrenalin secretion is increased during strong emotion and its action is to make the body as a whole more efficient in the crises which call forth the emotions of pain, fear, or anger. According to Cannon, "That organism which, with the aid of adrenal secretion, best mobilizes its sugar, lessens its muscular fatigue, sends its blood to the vitally important organs, and provides against serious hemorrhage, will stand the best chance of surviving in the struggle for existence."

There are many other ductless glands scattered throughout the body. Their secretions are all nicely balanced each against the others and there is a central nervous adjuster in the thalamus of the brain by

which this balance is maintained. For illustrations of the way ductless glands and other viscera co-operate with the sympathetic nervous system read Dr. Cannon's books cited at the end of the chapter. There is also a good account of them in Dr. Gordon's book on *Personality*.

CRETINISM

Some of the most spectacular triumphs of present medical practice have followed directly upon new knowledge about the ductless glands.

For ages past, one of the most pitiable forms of human defectives has been known as the cretin, miserable misshapen dwarfs stunted from infancy in body and mind. When it was discovered that these pathetic human derelicts owe their misfortunes to failure of the thyroid gland to form its normal secretion, and when this secretion was analyzed, it was found that a particular substance called thyroxin must be formed by this gland if the child is to grow normally. Without it growth in both body and mind is blighted.

If now a young cretin is given suitable doses of extract made from the thyroid gland, the child who was otherwise certainly doomed to drag out a miserable existence as a hopeless imbecile begins to grow. Bodily and mental development are resumed and in some cases they may come up nearly to normal. The thyroxin can now be artificially manufactured by the chemist from its simple ingredients, and the artificial product is as potent as the natural thyroid extract.

No dream of alchemist in his search for the Elixir of Life could surpass the actual accomplishment of

this wizardry of the laboratory. Both bodily and mental deficiency can be ameliorated by the same agent, that is, by adding a minute amount of a chemical substance to the body so that its defects are corrected. This is possible because the mental traits are bodily functions. A chaotic malformation of body and spirit is reordered and health and sanity replace deformity and mental darkness. The growing mind is as clearly a developmental change in the working of physical organs as is the growth in stature and physical strength.

NORMAL BODILY AND MENTAL TYPES

The proportions of the various activating chemicals present in the blood-stream are slightly different in all people, and these differences play some part in the growth of those bodily and mental peculiarities by which we tell one person from another.

Many attempts have been made to correlate types of body form with differences of temperament, disposition, and predisposition to disease. The most widely used scheme is that of Kretschmer, who distinguishes (among others) the following: (1) the pyknic type, with round heads, plump and stocky bodies, and short limbs; (2) the athletic type, with heavy bones and muscles, broad shoulders, and long limbs; (3) the asthenic type, slender, lanky, individuals, with narrow shoulders and long limbs.

Parallel with these differences in bodily constitution there are usually obvious differences in temperament and mentality. You cannot think of Mr. Pickwick any other way than as rotund and expansive in body to match the mental type that Dickens pictured.

A recent study by Wertheimer and Hesketh suggests also that each of these body types has a different predisposition to mental disease. That is, among the insane the patients who are classified as maniac-depressive, dementia precox, etc., tend in each group to show a preponderance of one or another of the general body types. This may help in forecasting the probable further course of an incipient mental disorder and so guide the physician in his treatment.

The Yankee has a world-wide reputation for energy and enterprise. He is a "go-getter." We say he lives faster and this is probably literally true. Some oriental peoples, on the other hand, adopt a more passive attitude, calmly awaiting what fate may bring to them.

There is a way to find out whether these placid people actually do live as fast as their more energetic neighbors. Most vital processes are chemical reactions and the total of these can be more or less accurately estimated. This the physiologists call basal metabolism.

Turner has found that the basal metabolism of Egyptians and Syrians is lower than that of Europeans and Americans. They are as leisurely in their internal chemistry as in their business dealings. Armenians are higher than Egyptians, Syrians, and Persians. Dr. Turner thinks this is constitutional for all these peoples, not merely a matter of adjustment to the slow pace of their communities, for Syrians who have lived for a long time in Philadelphia, Pennsylvania, show the same rate of chemical activity as those in Beirut. But of course a New Yorker

would say that the proof is inconclusive, for the leisurely city of Philadelphia cannot give a fair test. Dr. Benedict has still more recently studied the basal metabolism of many types of people and he also finds racial differences in rate of living as measured in this way.

Clearly these constitutional differences between people, their temperaments and emotional attitudes, depend on a large number of inherited and acquired peculiarities in very complex interrelationship. Just how the ductless glands operate in this complex has not been fully determined. Apparently they play a large part in it.

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CHAPTER XIII

THE VITAL ENERGIES

VITAL FORCE

BOTH popular and scientific notions of vital force are crammed with mysticism. This is natural but unfortunate. The simple fact is there are vital forces just as there are mechanical forces, chemical forces, and magnetic forces. They are all different manifestations of energy, different because the machines through which they work are different.

The forces of nature, we repeat, are all expressions of a common energy. How this energy comes to expression depends on the organs of expression employed. Wind blown through one pipe of a big organ gives the tone that we call "middle C." The same air blown through a pipe of different size and shape gives us a note an octave higher. If the pipe is of wood we get a tone of one quality, if of tin a different quality. In all these cases the energy that we start with is that of moving air. And the energy of the tone delivered again is that of moving air. But the tones differ because the shapes and materials of the pipes change the rates and forms of the air waves.

So we give all natural forces different labels—mechanical, thermal, electrical, and so on—depending on the mechanisms through which they play. Vital forces play through living bodies, which are different-

ly constructed from any other mechanisms that we know. Of course, the vital functions are different from those performed by any other mechanisms.

There are some vital processes for which mechanisms are not yet known and others whose mechanisms have been located but no one has yet discovered exactly how they work. A few biologists, many philosophers, and most other people have been inclined to look for the causes of these obscure processes outside the natural mechanistic system, in some supernatural or metaphysical realm. They look for mystical vital forces that have no natural causes, though they seem to have natural results in animal and human behavior.

This, of course, removes these processes from the domain of natural science entirely and relieves the biologists of any concern with them. But the biologists do not seem to welcome this relief. The organism seems to be a unity and they do not see how mystical vital forces, entelechies, or disembodied spirits can really act on mortal flesh and blood to give us the very natural behavior that we observe. This whets their curiosity.

The mystic principles are invoked only at the borders of our knowledge, and as we learn more about animal bodies and what they do many of the supposed magical vital powers are seen one by one to fall in line as natural functions of very real physical organs.

There are laws of electrical conduction through wires and fluids, of sound conduction through air and earth, of conduction of chemical change (oxidation) through a powder fuse. These laws are all different.

Now, when a nervous impulse is conducted through a nerve fiber, this takes place in accordance with still other laws. We find that nervous conduction is a complicated process involving some oxidation of tissue as in the burning of a powder fuse, some electrical changes as in the passage of electrical current through a fluid, and some other physical changes. Each of these chemical, electrical, and other physical processes, taken by itself, conforms with the laws of similar processes in the inorganic realm; but the pattern of combination of these elementary inorganic processes as we see it in nervous conduction is found only in living bodies. This is what we mean by saying that nervous conduction is a vital process. The "vital force" exhibited is natural force manifested in ways found only in living machines just as magnetic force is found only in machines of a different sort. It is now clear that life is not a miracle unless one chooses to say that all nature is miraculous.

Mechanistic biology is the only kind of biology that has scientific standing. This is the biological method everywhere, the discovery of living mechanisms and how they work. Knowledge of the laws of these mechanisms gives us control over vital processes—how to improve our crops and farm animals; how to keep well, to cure disease, to improve the health, efficiency, and happiness of the human race.

TRANSFORMATIONS OF VITAL FORCES

The energies of physiological gradients and nervous impulses are typical vital forces. There are countless others, equally specific and all related in a systematic way. The sources of these energies are

known and also many of the ways in which one is transformed into another.

When a sense organ is stimulated measurable amounts of external energies of mechanical pressure, light, heat, and so on are transformed at the surface of the body into nervous energies of excitation and conduction and these too can be measured. Can these transformations be reversed? Yes, they can. The energy transmitted by a motor nerve from the brain to a muscle starts activity there which comes out as mechanical work and heat. Everybody knows this. In other cases nervous energy can cause light-production, as in a firefly, or the generation of high potential electricity, as in the electric eel—in all these cases through the intervention of very special protoplasmic organs.

This sounds simple, but it isn't, because most of the energy for all of these activities is supplied locally by the organs that perform the work; it does not come in from the outside with the stimulus, but each step of the process merely serves as a trigger to set off the next. The energy transformations in even the simplest reflex are so very complicated that it is impossible to follow them through with accurate measurements.

In a reflex the energy of the external stimulus is not simply reflected from the body in modified form but unchanged in quantity. The energies delivered are often far in excess of those received. The total intake of energy over a definite period and the total output of energy over the same period can be measured with the calorimeter with considerable accuracy, but this does not tell us what is going on inside.

It does tell us, when the energy output is greater than the intake, where the extra energy comes from. It comes from the consumption of the reserve tissues within the body, for the body loses weight just enough to provide the excess energy.

THE ENERGY OF NERVOUS CONDUCTION

It was long supposed that no physiological work is done when a nervous impulse is transmitted over a nerve fiber, because nobody could prove that oxygen was taken up or heat produced, as in other vital processes. But with more sensitive instruments it has now been shown that a minute amount of the substance of the fiber is consumed and some heat is generated. All that was necessary to show this was more sensitive measuring apparatus and greater skill in using it.

Tashiro with a very delicate apparatus that he called a "biometer" proved that the resting nerve uses a small amount of oxygen and gives off a little carbon dioxide. It breathes like all the other tissues. When the nerve is excited this process of oxidation, or combustion, goes on about twice as fast and more than twice as much tissue is burned up. More recently Parker by an entirely different method and with simpler apparatus showed the same thing.

As in all other processes of combustion, some heat is produced, but so very little that it has not been detected and measured until a short time ago. Gerard found that a single impulse in one gram of nerve releases a millionth of a calorie of heat. One pulse of nervous conduction traveling one centimeter

in a single nerve fiber generates a million-millionth of a calorie of heat.

The heat generated in nerve, like that produced in muscle, is divided into two parts. There is an initial phase lasting a few thousandths of a second, probably not much longer than the nerve impulse itself. Then there is a delayed phase which may last ten minutes and contains nine-tenths of all the heat produced. The fact that other experimenters overlooked the delayed phase may explain their failure to demonstrate any heat at all.

From these experiments it is clear that energy is not transmitted along a nerve fiber the way electricity is conducted over a wire. The energy of transmission is supplied locally as it goes along, more like the burning of a fuse. But not exactly like the fuse, for there are many other things going on in the nerve besides combustion of tissue that we cannot describe here. That is why the nerve, unlike the fuse, can repair its own waste so rapidly.

Nerve fibers are often said by physiologists to show no fatigue, but this is an error. They apparently do not tire because actually they rest a little while—a very little while—between successive pulses of activity just as the heart does. Between heartbeats there is a pause when it is not working. In fact, the heart is resting more than half the time and that is why it can keep on beating steadily for threescore years and ten unless something else besides fatigue stops it sooner.

So the nerve fibers also rest. After a nerve is excited there is a short time (less than five-thousandths

of a second) when it cannot be excited again. This "refractory phase" of the physiologists is a period of rest. Short as it is it is sufficient to enable the fiber to build up its exhausted substance and be ready for another pulse of activity. The ability to do this in so short a time is one of the evidences of the remarkable construction of the nervous machine. It does remarkable things because it is very differently made from any other parts of the body.

After a nerve fiber has been excited it rests completely for a few thousandths of a second during the refractory phase before it can transmit another nervous impulse. Then it takes an additional period of about ten minutes to bring the fiber back to its completely rested state. Rapidly repeated stimulation continued for a long time depresses the activity of the fiber, which then shows an enduring fatigue though it can still conduct nervous impulses.

Gerard says, further, that in a frog's leg the energy expended by the nerve in carrying a message to a muscle and causing it to contract is about one-millionth of the energy that the muscle expends in a single contraction. This quantity of energy of nervous conduction is much too small to be recorded by any calorimeter ever built for study of energy changes in the live body. Presumably the nervous energies going on in the cerebral cortex during thinking are of the same order of minuteness. Is it any wonder that the early calorimeters did not measure thinking? But recently Dr. Benedict has so improved his calorimeter as to be able to measure the bodily energy expended in thinking. Hard mental work increases the total energy output of the body only about 3 or 4 per cent.

He finds that working difficult problems in mental arithmetic for an hour requires an energy expenditure of two and a half calories—and this is about the same amount of energy as we get from eating half a peanut. But it can be measured. The value of the work of a machine cannot be measured by the size of the fuel bill.

During the transmission of nervous impulses there are obvious changes in electrical potential in the nerve. This is the so-called negative variation, or action current, which can easily be measured with a galvanometer. This action current may be strong enough to excite a nervous impulse in a resting nerve that lies in contact with the excited nerve.

The electric properties of nerve and muscle have been known ever since Galvani hung some frogs' legs on an iron railing with copper hooks and saw them twitch from the electric currents generated. He published his more systematic observations in Bologna in 1786. He made an arc of two different metals and when one end was put on the nerve and the other end on the muscle he got a stimulation of the nerve and a contraction of the muscle. Galvani's frogs started an immense amount of fundamental research on the electric properties of nerves that is still going strong.

RADIOACTIVE ENERGY

Another illustration of the way very small amounts of energy may play important parts in the control of bodily processes is mentioned by A. P. Mathews. He cites experiments of Zwaardemaker, a Dutch physiologist, which show that the potassium of the body is radioactive. There are 40 grams (about an ounce) of

potassium in the human body, and though potassium is only about four one-millionths as active as radium this small amount of radioactivity is enough to do remarkable things. It is computed that 80,000 atoms of this potassium are decomposing every second and discharging a like number of electrons at a velocity nearly as great as light. The total amount of work that they do is only about a thirty-five-billionth of the whole internal work of the body (what is called basal metabolism). This work is done mainly in nerves and muscles.

Small as this amount of work is, a single one of these 80,000 electrons has 4,000 times as much energy as that required to stimulate the retina by the faintest perceivable light. "A star of the first magnitude twinkles at night with 30 to 40 times less energy than that of a potassium atom when it explodes."

Obviously very slight changes in the rate of this decomposition of potassium or in the places where the energy of the liberated electrons is applied in the course of nervous conduction and muscular contraction may profoundly affect the pattern of the performance of our bodies in states of nervous excitement or depression. Zwaardemaker suggests that this may be the energy which sensitizes the synaptic junctions between neurons and so determines the direction of flow of nervous energy in all reflex and conscious work. This is theory, but the established facts open up interesting fields for future research regarding the sources and apparatus of the nervous energies.

All living substance is radioactive and in regions of rapid growth the emanation is strong enough to affect a photographic plate. When actively growing

tissue is artificially treated with X-rays or radium very remarkable changes in the processes of growth take place. This is the secret of the recent successful treatment of some cancers and other diseases by X-rays and radium and of the amazing effect of X-rays upon hereditary characteristics of the germ cells that have of late so excited the students of genetics. This field of research is very new and gives promise of opening up secrets of vital mechanisms which ten years ago no one could have dreamed of.

THE PSYCHOGALVANIC REACTION

There are many other far more delicate ways of detecting the work done within the human body than the calorimeter. One of these employs a very delicate galvanometer which records electric currents generated within the body by its own activities. One form of this is the electrocardiograph used in the hospitals for detecting obscure abnormalities of the heart action. Any slight change in the muscular action is instantly recorded as a change in the electric potential of the body.

The same principle has been applied to the study of energy changes going on in the body during a wide variety of bodily and mental processes, including emotional excitement. This is the so-called psychogalvanic reaction.

One of the earliest and simplest ways of applying this test is described by Mathews. The experimenter put a moistened electrode on the palm of Dr. Mathews' hand and another on the back of the hand. These were connected by a wire with a galvanometer in the circuit. No battery or electric generator was

used. The galvanometer recorded only electric currents generated within the body and manifested as difference of potential between palm and back of the hand. The galvanometer came to rest. Then the experimenter picked up a pin and started toward Dr. Mathews with the remark, "I am going to prick you with this pin." He did not actually touch the skin with it, but Dr. Mathews confidently expected that he would and he had the corresponding emotional thrill. There was an instantaneous increase in the current through the palm of the hand and the galvanometer recorded it with a wide swing. An emotional upset is bodily work with change in electrical potential which is easily measured.

This simple apparatus has since been improved and refined and now in some insane asylums the psychogalvanic reaction is used in a routine way to determine the emotional balance of the patients in their alternating phases of depression and excitement.

We shall have occasion to refer to this reaction again in the chapter on the emotions, where it is pointed out that the physiological and especially the psychological questions suggested by the psychogalvanic reaction are still very unsettled. Here it need only be added that the bodily activities that cause the electrical changes recorded on the instruments are chiefly in the muscles of the small arteries, the sweat glands, and the sympathetic nervous connections which control these. The activity of the brain may also take some part, though probably a very small one; but no experiments have yet been devised to settle this point.

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CHAPTER XIV

HOW LIVING MACHINES ARE MADE

ANIMALS' INVENTIONS

ANIMALS have been inventing machines for hundreds of millions of years before man ever appeared on this planet. Beavers have built dams, bees have built honeycomb, coral polyps have built reefs. These are all contrivances to help these creatures along in their domestic economy, in the details of their family life and housekeeping.

There is no reason to believe that these mechanical devices were invented in the same way that an engineer goes about it to design a practicable four-wheel brake for a motor car. The engineer knows what he wants and he knows enough about mechanical principles and tensile strength of materials to figure out in advance a number of designs that might work. He tries them out and where defects appear he realizes that he does not know quite enough. So he does some scientific research, or hires a laboratory drudge to do it, until he discovers some facts or principles that he did not know about before and that fit the situation. The gaps in his previous experience he fills by getting some more experience.

Bees apparently did not work that way when they designed the honeycomb. Without having any clear ideas of what they were about or any conscious desire to do it differently, they went on gathering honey and pollen to feed their own mouths and their babies,

as their ancestors had always done. But they did not all do it in just the same way, and some arranged the cradles for the babies and the food supply for them a little differently from the others. At first, in the solitary bees, the nest is a simple tube with eggs laid in it and a packet of bee-bread (prepared pollen) for each egg, just enough to take care of the newly hatched young ones for a time. Later they are fed by the mother.

But in view of the uncertainty of the weather and the danger of long periods of storm when the mother-bees cannot get out to collect honey or pollen from the flowers to keep up the food supply for the brood there is always a risk that the new-hatched grubby young ones will starve to death. In good weather bees gather honey diligently, not from any deliberate motives of thrift, but just because they are made that way—they naturally keep working as long as the sun shines.

If more food is gathered than is needed for present use, the surplus is not thrown away but it is put into any containers that are handy. Some, as already mentioned, is laid away with the eggs in the nest. The rest must be stored somewhere else. Empty cradles or egg-capsules would do for this and this is what the bumblebees use. Those bees that collected the most surplus food and stored it safely so it would not spoil would have a better chance to have enough for the growing family during long spells of inclement weather. The broods of the more shiftless ones perished. The survivors transmitted their traits to their offspring and so storage of reserves of honey and pollen comes to be the rule and everybody does it.

The mother-bumblebee, like a hen, broods her eggs. She lays by a supply of honey and pollen in advance and stores these in honey-pots and pollen-pots which may be empty egg-capsules or they may be made of beeswax for the purpose. She is now secure against shortage of food while she is brooding the eggs and afterward when the youngsters have to be fed. These habits probably grew up blindly—not deliberately or with carefully planned foresight—some bees behaving one way, some another, and the more favorable variations surviving in times of emergency and hardship. There is no evidence whatever that the bees know why they do these clever things. They have no intelligent foresight of the change of seasons or knowledge of the engineering principles of hexagonal prisms as economical containers of fluid.

Finally, in the course of time—a lot of time—some parts of the comb were set aside for honey and some for babies. Those hives that did the neatest job of this and stored the largest amount of honey so that it would not spoil had the best chance to survive the hardships of winter. The less competent hives died out and so produced no new swarms next season. Now we have a special race of honeybees that always build comb for the storage of honey.

NATURAL SELECTION

This is Darwin's principle of natural selection applied to the invention of a machine—the honeycomb—by a species of insects. When the process is complete we have not only a new device for the storage of food but we have also a new species of honeybees, *Apis mellifica*, which is different from the old one

from which it was descended. At the same time that the honeycomb was invented the species *Apis mellifica* was invented.

The honeycomb and the bees that make it are new inventions, not designed by deliberate purpose and scientific experiment, but unintelligently by trial and error or trial and success. The failures perished; the more successful hives survived. This "survival of the fittest" goes on in a cumulative way from generation to generation until a satisfactory adjustment to the conditions of life is attained, until a practicable honeycomb is evolved. The change goes on and endures because from generation to generation the bodies of the bees themselves are changed and these changes are inherited.

Bees behave in this way because of the way they are made. They cannot do it differently. It is their nature to do it the same as it is the nature of a nail-cutting machine to make nails. And again the bees were made this way naturally by a process of evolution which works mechanically, that is, in accordance with natural laws. The laws of evolution are laws of natural mechanics; they are the laws in accordance with which the new kinds of animal bodies which we call new species of animals were contrived.

To account for this ingenious and wonderfully beautiful adaptation there is no more reason for calling in mystical vital forces or any other kind of magic than there is in the case of the formation of a new river by natural agencies. Both show adaptation and some of the mechanisms employed are well known. We know from the record of the fossils in the rocks that for more than a hundred million years

similar changes in the kinds of animals that have lived have taken place and that these changes have gone on in orderly fashion. The rules or laws of this order can be discovered. Some of them have been. Darwin's law of natural selection or survival of the fittest is one of these laws that is well established. This law has survived all the attacks that have been made upon it and today it is more firmly intrenched in scientific teaching because it has withstood so searching criticism. There are many other laws of evolution beside Darwin's, doubtless many that we have as yet no notions of.

The living body is a machine that works mechanically and that arose mechanically, that is, in a natural way in accordance with the laws of vital processes. Living stuff is so constructed that it behaves in specific ways in particular situations, and it changes its construction to fit new situations.

When the mechanisms of inheritance (chromosomes and the like) are changed by any means, there will be a change in the offspring and out of these heritable variations or mutations new varieties and species may arise. They will endure provided any of them are adapted to the existing conditions of life. Those individuals that are not adapted to the conditions perish without offspring. This apparatus of reproduction is part of the complex machinery of evolution, of species formation. It is also the most interesting part of the mechanism by which new individuals are started on their separate careers. The new persons are made out of materials supplied by their parents. Both ordinary reproduction and the evolutionary process are cases of natural creation.

MECHANISMS OF INHERITANCE

Perhaps the most dramatic incident in the long history of biology is the story of the discovery of the recondite details of the mechanisms of inheritance. This story is not finished yet but the instalments already published are intriguing. Within the memory of living men the details have been accumulated one by one and assembled into a scientific structure that now stands where before was only superstition and old wives' fables of storks and maternal impressions.

Malinowski tells us that there are primitive peoples living today that do not know that children have fathers. The mother conceives a child by magic. Two centuries ago the most educated people were not much better informed, and today in our cultured communities hundreds of innocent girls come to the marriage ceremony in the same state of blissful ignorance —a bliss that too often is rudely extinguished in shame and anguish.

More than sixty years ago the monk, Gregor Mendel, as he tended the flowers of his garden, wrote the first chapter of the story of modern genetics and pointed the way to a method of study of cross-breeding that in our time is bringing order out of chaos, science and power to control heredity out of mystery and necromancy.

Then came refinements of microscopical technique which permit us to see the chromosomes, those pious vestals that guard and transmit the sacred fire of life from parent to child, and to demonstrate some of the recondite machinery of the germ plasm in the transmission of particular characteristics. Knowing now something of the mechanism of hereditary trans-

mission, it is possible to control its workings in ways that the most fervid magicians of bygone ages never imagined. A single series of these investigations carried on for many years by Professor Morgan of New York is said to have involved the counting and sorting of over twenty million fruit-flies.

New methods of attack upon these problems are opened every year. The latest marvel is the discovery that germ cells treated with X-rays yield heritable modifications or mutations in the offspring more frequently—many hundred times oftener—than would normally occur. This gives the animal and plant breeders a chance to have in a single experiment a thousand-fold more modifications for experimental cross-breeding purposes than Burbank could get in the usual natural way by many years' search among the millions of plants that he raised. A brief summary of these revolutionary investigations is given in the article by Muller cited.

The field of genetics gives the most striking illustrations to be found anywhere of the nature of the vital mechanisms and the practical control of vital processes that is gained as soon as these mechanisms are adequately understood. This is the machinery by which new individuals are propagated by animals and plants generally and also by which new varieties are being created under natural conditions out-of-doors and under artificial conditions in the laboratory and farmyard.

MAKING NOVELTIES

Natural machines like rivers and volcanoes have beginnings. They were made out of something which

was different and they were made by the interplay of physical forces acting on various kinds of stuff. The schoolboy's definition of a volcano is graphic and adequate for his purpose, "A volcano is a mountain what is busted and squirts out stuff." The geologist takes up the question here and asks, What busted the mountain and where does the stuff come from?

So the biologist observes many dramatic scenes in the living world, and he wonders how they work and what keeps them going. He finds answers to some of his questions in most unexpected places—in ditch-water, fishworms, fruit-flies, and human brains. Fish-worms and jellyfishes live modestly but very well, provided they stay at home. A thorough study of the mechanism of living in these lowly creatures has shed a surprising amount of light on the general question of how we live at all and how to do it better. Worms live, as far as they go, by pretty much the same rules as ourselves, and some people, we are told, live very like jellyfish.

We find that the human body, like all the rest, behaves like a machine because it is a machine. But it is not the same kind of a machine as a rabbit's body or a motor car. That is why it does not twiddle its whiskers when hungry or eat gasoline instead of meat and potatoes.

Some of the scenes in this enthralling drama of life have taken an amazing amount of time. But there seems to be plenty of time and we have several chronometers by which we can measure these millions of years—none of them very accurate but good enough for our present purpose. There is the unending procession of created species, crabs and butterflies and

serpents and eagles and mice and men. Each kind comes on the stage and plays its part for as long as it can hold its place in the spotlight. Some species have endured for tens of millions of years almost unchanged; others are as ephemeral when measured by geological time as the mayflies are when measured by our span of life.

These unnumbered species of past and present time have all been created lawfully; they did not just happen by "fortuitous concourse of atoms" or in any other disorderly way. Each emerged from some pre-existing species back to the unknown Eozoic ancestors of all of them. We now have some knowledge of how nature works in making new living things, how new vital patterns emerge.

EMERGENT EVOLUTION

It is a pity that the idea of emergent evolution in its recent form came to birth in an atmosphere of mysticism. Its leading sponsors seem to regard the natural mechanistic cosmos as something eternally limited from the beginning (or from no beginning, as the case may be), but not self-contained. That is to say, its own potentialities are all predetermined and nothing new can occur except what is foreordained and already there in the mechanical organization of the system; and yet new potencies can be injected into the system from a mystical realm of entelechy, *élan vital* or magic.

To a naturalist who is a radical mechanist this sort of emergent evolution seems like a hybrid monster which cannot be viable in our practical world where we must adjust to events which follow in

natural cause-and-result sequences. A mechanistic scheme which breaks down at even one point where a new "emergent" comes in is no safe guide for scientific research or for practical affairs. If life, mind, purpose, or freedom are non-mechanistic and to be accounted for only by intervention or interpolation from supernatural realms, then why not gravitation, chemical affinities, and all the rest? We are back to the fetishism of the most primitive culture and further advance by the scientific method is impossible.

No, this is not the way out. The thing breaks down most hopelessly where we need it most, in our human adjustments. A valid science of human biology cannot be built on such an insecure foundation.

Radical mechanists are fully aware of this and some of them meet the difficulty very simply—by ignoring the troublesome factors of the problem and, for instance, leaving out of consideration those common attributes of human experience that we call our spiritual powers. There is no evidence that these phenomena exist in inorganic nature. They seem to be new. But nothing new can happen in a mechanistic universe. Therefore these phenomena did not happen. The appearance of their presence is illusory. The same argument may be applied to life itself. Once there was a time when there was no life. Life is new. But if new things don't happen then life too is an illusion.

Let us examine the major premise of this argument, that nothing new can happen in a mechanistic universe, only the unfolding and elaboration of what was already there in accordance with laws that existed from the beginning of eternity. It looks as if

this were not true. There probably was a time when the planet on which we live did not exist, and there certainly was a time when there were no horses on it. Both of these things at one time were new. What the mechanists mean then is that when these new things appeared they were naturally caused and the natural laws in accordance with which they appeared can be discovered by scientific research.

This is excellent. Horses did not exist on this planet before life appeared on it. Naturally the laws of the evolution of horses did not appear before there were horses, and there were no laws of organic evolution before there were organisms. Then these laws too at some time were new.

Or perhaps we are wrong about this last point. Let us refer back to our discussion of the laws of nature in chapter v. What are these natural laws? Rules or ordinances laid down by God or something at the beginning, rules which all natural processes and all living things must obey? No. They are merely our formulation of what we have found out about the way nature works. So you see the natural law was not there and cannot be predicated as valid before the process that exemplifies that law was in operation. If the process is new, the law is new.

Any conception of evolution that leaves out the appearance of actual novelties, kinds of things and events that were not there before, is untrue to the observed facts. From this it follows that new laws of the behavior of living things come in when the vital mechanism changes from one form to another.

This seems to be a hard truth for many naturalists

to grasp. We are so accustomed to thinking of laws as commands given by somebody to which obedience is demanded that we read into the natural laws which we have formulated a notion of necessity. This amounts to saying that nature must obey the "laws of nature" that we have enacted.

This seems like a rather large order, even for a mechanist. If this is the way things are, mechanistic biology is indeed bankrupt. The job is too big for us, and we would better give it up forthwith and call in some supernatural omnipotence—or what have you?—to take it off our hands, the whole of it, not merely troublesome spiritual phenomena.

But some of us mechanists do not feel like demanding so much. We do not claim to understand the original sources of our cosmos, its materials, its energies, or its laws. But we are able to observe something of how these things are working now and to read some part of the history of their transformations. In the course of this history novelties have emerged from time to time and they appear to come by the natural working of the cosmic machine. Some of the laws of their emergence have been discovered and we hope that more will be.

Creative evolution appears to be a discontinuous or "jumpy" process because we see the end-results only of the recombination of simpler elements at each step. But the continuity of causally related processes is unbroken. When a new "whole" is made out of diverse parts the properties of the whole are different from those of its separate parts. This is where the novelty comes in. And these properties are real-

ly new. The evolutionary process is not a mere unwrapping of what was there before. As Patrick says, "Every new form is a plus—a new creation."

A critic of this statement (*Journal of Philosophy*, vol. 28 [1931], p. 495) remarks, "the mechanical character of a process stops precisely where novel, creative, then unpredictable aspects of the process emerge." I wonder if this philosopher would regard the work of an adding machine as mechanical. Every sum that it computes is a novelty. It has created a product that was not there before. In this case we can predict the answer because we know the laws of the machine that we have made.

If I mix two parts of hydrogen with one part of oxygen and ignite the mixture, it burns and the product of the reaction is water. Is this a mechanical process? The water has new properties that are quite unlike those of the two gases from which it was made, and no chemist could have predicted these properties from a study of the elementary gases. We found out by experiment that the properties of water are related with those of its constituent gases as they are, and *now* we can predict what will happen when hydrogen is burned in oxygen and what kind of a product will be made.

The philosopher says, "in the sense of cause which is important for science, it is identified with antecedents which enable us to predict consequences, and in this sense creative or novel elements are not caused and not mechanical." To this the naturalist replies: If I find, when novel elements do appear, that they come in an orderly way and that I can learn the laws of this order and so predict the conditions which must be set up for repeating the process, then I infer that the result obtained is naturally caused, and this is what I mean by a mechanical process. In the case of still other novelties, where we have no hope of ever being able to repeat the process, like the fall of a

meteorite, we still believe that the thing is a naturally caused mechanical event. When we know more of the laws of meteors we may be able to predict the fall of a particular meteor; but in the meantime no naturalist will admit that meteors are either uncaused or non-mechanistic.

To the mechanist, then, emergent evolution means simply lawful evolution, not capricious change. There are laws of change as well as laws of stability; and the laws of change will themselves change with the changes from which they are deduced. The laws do not make the changes; they are merely our way of recording such uniformities as we have observed in particular cases or systems of change. We are not only discovering from time to time laws of nature that have been in operation as far back as we can explore, but we are finding out the times or stages in evolutionary sequence when the laws of evolution themselves changed. We cannot forecast what changes in the laws of nature may occure in the future. Only omniscience could do that. The best that we naturalists can do is to observe what has happened and formulate the laws or uniformities of these events *ex post facto*. Then we know that events will hereafter go on in accordance with these laws unless or until new changes are made in the mechanisms in operation.

We can survey the past and see that new things have emerged, when they emerged, and how they emerged. We may also peer into the future as far as the laws now applicable extend. But we have no basis for forecasting what changes in these laws the future may have in store except in so far as past changes have shown trends.

The evidence, to be reviewed later, seems to indicate that mind has emerged in this natural way from unconscious vital activities. The laws of its emergence have not been discovered. Neither have the laws of the emergence of life from lifeless matter. Both of these changes in the laws of nature seem to have taken place, and they are very fundamental. Within historic times there have been similar, though less radical, changes in the laws of human migration, education, religion, political organization, and economic adjustment. These we already know something about. Who is rash enough to predict what further changes another thousand years may see?

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CHAPTER XV

HOW MEN ARE MADE

MAKING THE INDIVIDUAL MAN

THE early stages in the fabrication of every person go on in accordance with the laws of heredity already mentioned. The first raw materials are two microscopic flecks of protoplasm, the maternal and paternal germ cells. These carry in their organization an amazingly complete epitome of the characteristics of the race and family within which they were grown so that the offspring which results from their union is a blend of the characteristics of the two families or a composite made up of selections from both of them. And it is more than this, for the interaction of the two germ plasms may result in combinations of characteristics never before produced in the ancestry of either parent—such as the sporadic appearance of a genius or a moron or a crank.

We are still in the dark about many details of how heredity, growth, and differentiation go on; but the increase of our knowledge during the last few decades has been enormous. Many of the mechanisms at work and laws of their operation are accurately known—chromosomes, mitotic figures, mutations, Mendelian ratios, physiological gradients, electrical currents and polarities, to mention only a few. These details cannot be taken up here. They are readily accessible in many readable books on genetics and embryology.

The process of individual development is not in principle different up to a certain point from the way the river uses its raw materials to make it what it is; or, up to a certain further point, from the way the species horse and the species man made themselves by successive adjustments to their respective environments. The specific internal or intrinsic organization of each of these things was a significant part of the creative machinery, and a progressively more important part as we go from the inorganic to the higher organic levels. At the top of the series we come to the creation of the individual human personality. And here the intrinsic factors are supremely important. What these intrinsic factors are and the mechanism employed is the main theme of our further inquiry into the natural history of human nature.

EVOLUTION OF HORSES AND MEN

We have commented on the way men make machines, how corals and bees and beavers make machines, how inorganic nature makes machines like rivers, how species of animals were made by a process that we call organic evolution, and how individual living bodies are made by various agencies included in the terms heredity and environment.

The river goes through its cycle of youth, maturity, and old age in conformity with the laws of continental elevation and degradation. The exact sequence of events in any particular river will depend on thousands of conditions which interplay in an orderly but very intricate way. The broad outlines of this history can be read with considerable accuracy in each case.

In a similar way we know the history of the evolution of the horse, more fully indeed than that of any other backboned animal. Starting with the little Eohippus, the size of a fox and with four toes to his feet, we can read the progressive change from one geologic epoch to another as first one toe and then another was dropped until the single surviving toe was enlarged to form the hoof. The actual specimens, accurately seriated, are in our museums.

Knowing also something about the climatic changes that went on during these epochs, we can see some of their causes. The ancestral precursor of our horses lived in forests and his four toes splayed out in the soft ground and kept him up. As the forest was replaced by hard-surfaced prairie the firmer ground needed a more solid foot and the hoof replaced the four toes. Natural selection and doubtless many other principles were exemplified in getting this result. The foot at each stage was sufficiently well adapted to give the fleetness necessary to preserve the species from extinction.

The history of the evolution of man's body is more fully known than that of any vertebrate except the horse. These changes occurred a long time ago and some of them in out-of-the-way places (Java, South Africa, Mongolia) that have not as yet been fully explored. New "missing links" are coming to light every few years. It would take too long to review this history here, and it has been well done by others.

When an arboreal primate came down from the shelter of the treetops he must protect himself by concealment, by acquiring great strength, or by his

wits. Some chose one way, some another. The first two ways were not very successful under modern conditions. Most of those who tried them are now extinct. The few survivors—gorilla, chimpanzee, orang—are rapidly disappearing. But wits survived. Out of a partnership of a good brain and a hand fashioned for making and using tools primitive man emerged.

Emergent evolution. New things coming out all the time. This is creative evolution. The creator is the evolving thing itself.

A river is a self-regulating mechanism. So is a horse or a man. But the laws or rules of the regulation are very different in the three cases. The animal body can do some things that the river cannot. The river before it dies does not hatch out a brood of little rivers like itself and then send them out to find congenial places to run their courses and grow up. The river does not intelligently attend to where it is going and avoid dangerous places the way a horse does. The river does not look ahead and plan its career and take satisfaction in achieving its ends the way a man does.

The river system is self-made. That is, the water that flows, the drainage basin through which it runs, and all the natural things and events that play upon these and influence their behavior form a unitary system which begins, grows, changes its form, and does an immense amount of work in a methodical way. Everything that happened was the result of what happened before and the cause of what happened next.

The horse is self-made in a similar way. Our horses came to be what they are because at every

stage in this evolutionary history the horse's body was changing to adjust to changes in his pastures, the food he had to find, and the enemies he had to avoid.

The human race is self-made by a similar process. The ancient anthropoid (a Dryopithecus of some sort) from which man arose was very different from the little Eohippus from which horses came. The food that they ate and the things they did to get it were different. The raw materials out of which mankind was made were different from those from which horses were made and the whole process of manufacture was different in detail. Yet the biological laws running through were fundamentally the same in most respects, just as there are many engineering principles common to automobiles and airplanes.

The individual man to some extent is self-made in the same sense as the river is and the Genus Homo. He is not molded passively by environment any more than the river is; indeed, to a far less extent, for in making a man out of a babe his own reactions to the situation in which he grows up have relatively more to do with it. He is changed day by day by these responses that he makes, so to this extent, at least, he participates actively in his own development. Part of this change is brought about wholly unconsciously, but he is conscious of some of these adjustments and the part played in his development by this awareness of what is going on is something that we must inquire into.

The man purposely attends to his self-control and self-culture more or less. The river does not consciously attend to its self-culture at all. It does make itself grow and behave like a river, but not because it

wants to or by deliberate purpose. Nor did the little ancestors of our horses make up their minds to slough off their unnecessary toes and grow up to be noble racers. They grew as they did because the organization that they already had behaved that way in the changing environment in which they lived. Primitive man emerged from a more primitive primate stock in the same way, not by planning to make himself an inventor or a philosopher. These simple biological adjustments were later supplemented by more efficient conscious processes with the aid of language and ideas.

When intelligently directed or purposeful control of social progress and of personal development did come in it was again a new thing under the sun. It probably emerged gradually, and only very recently have we discovered how much we actually can do in this field. We could do a great deal more if we would pay more attention to what we already know about it and make a serious business of self-culture. This is what education is for; and it is hard to persuade either children or grownups to take the business of education very seriously.

In each of the cases mentioned the thing we started with had some particular kind of organization that worked in some particular way in the situation where it was. Then two things happened. First, the external situation changed, then, second, the internal organization of the thing itself changed in correspondence with or adjustment to the external changes. Neither of these two changes acting by itself alone could have made a river or a race horse or an in-

ventor. But the two systems of changes acting together and reacting one on the other did do these things, in each case in its own particular fashion.

Parallel with continental elevation the river began to erode the land and make its channel. Parallel with similar physical changes and with changes in the animal life with which they must compete the ancestors of horses changed internally to fit the new situation. Parallel with some such changes in the course of events in the physical environments of the ancestors of mankind the bodies and the behavior of these anthropoids, these primates that were almost human, also changed in adjustment to new conditions. As already mentioned, some of these anthropoids changed in one direction and became apes as we know them today; others changed in a different direction and became men—they became you and I and other people.

ORTHOGENESIS

Will a chimpanzee ever become a man? Probably not, for the same reason that a pig will never become a horse. There was an animal once that was neither a pig nor a horse, but some of its descendants became pigs and some became horses. After one of these lines of descent got started in the direction leading toward pigs, the subsequent modifications of internal structure could go on only in this direction because each successive step had to be taken from the place where it was then, not from the place where it was at the beginning of the process. The creation of any new species can be done only by using the raw materials at the moment existing in some living species. Pigs

can become better pigs and horses can become better horses, but better horses cannot be made from better pigs.

Evolution is an irreversible process. A given evolutionary trend having once begun, it continues in that general direction because bodily structures tend to be inherited unchanged, and when changes are made these must be changes in what is then present. So when an ancestral pig begins to enlarge two hoofs on each foot it is not so easy to change the pig type to the horse type with one hoof on each foot as it is to improve each type along the line already started.

This tendency of evolution to keep on going in any one direction which once gets started is called directive evolution, or orthogenesis, and some naturalists have sought mystical explanations for it. It is seen to be a perfectly natural process as soon as we get a sufficient understanding of the mechanism of evolution.

Now, of course, this does not tell us how divergent evolutionary trends were started in the first place. Horses and pigs began to diverge from a common ancestral stock, and at the beginning of this process the two lines of descent may have lived side by side in the same pastures. Why did they ever begin to develop differently? That is harder to answer. Perhaps because for some unknown reason of internal organization one line developed different habits from the other and selected different food, or because one wandered into a region where different beasts of prey were abundant or for some other reason adjusted its behavior to different features of the environment.

Once this different mode of life was established and fixed in the hereditary organization of this line, further divergence from the other line follows by the mechanism already mentioned.

We have dwelt upon this history of the divergent evolution of horses and pigs because it is very well known from the study of fossils and one does not have to theorize about it so much as we do about the ancestry of the human race. Yet we have enough knowledge of the fossil remains of the ancestors of man to feel pretty sure that the history was very similar to that already sketched. Those primates who were our human ancestors diverged into ape and human lines in much the same way as horses and pigs diverged from a common stock. In both cases it was differences in the way the internal organization reacted to the various features of the environment that set the trend of the evolutionary process. In both cases the process is now irreversible. No existing apes are likely to become men because they have settled down to a different kind of life. Primitive man got ahead of them in ability to live by his wits and the apes will probably never catch up with us now.

SUMMARY

Looking back over the various kinds of mechanism of which we have been speaking, there is general agreement that the things we study in astronomy, geology, physics, and chemistry have come to be what they are by natural means, not by magic. Most biologists agree that plants and animals too have grown up by a natural process of evolution and that the

process is mechanistic throughout in the sense that the agencies employed are all natural lawfully ordered events. This applies also to the human body.

When it comes to the human mind the case is not so clear. In this chapter we have assumed that mental evolution is also a natural process. It would seem to follow from this that we must find a place for mind also in our mechanistic system of nature. Can we make good on this assumption?

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PART III

MECHANISTIC PSYCHOLOGY

CHAPTER XVI

WHAT IS PSYCHOLOGY?

MECHANISM AND MIND

WHEN we attempted in an earlier chapter to find a satisfactory definition of mind and/or consciousness we had to give up the search and let the question rest with an appeal to the personal experience of each one of us. The psychologists do not seem to have had any better luck with the definition of their science, for scarcely any two of them agree upon what it is that they are studying.

Some of them resolve the problem very simply by saying, Psychology is whatever a psychologist is interested in. And this, in turn, would seem to resolve itself into the question, Who supplies the pay check? For, so far as an outside observer can judge, the interests of some professors of psychology are identical with those of some of their colleagues who call themselves physiologists or zoölogists and draw their pay from a different budget.

When we first broached the question of thinking machines, it was concluded that before deciding whether any machine can think we should try to agree upon what we mean by a machine and by thinking. Lifeless machines and living machines have been surveyed in considerable detail, and we have arrived at a radically mechanistic biology.

The human organism fits into this mechanistic

scheme well enough so far as our objectively observable behavior is concerned. The same biological laws run through animal and human nature in countless instances. We eat the same kinds of food and digest it in the same way. We breathe the same air in the same way. Our muscles and nerves work the same way. Of course, there are differences between us and cats and monkeys, but our behavior is enough like theirs so that we call some people "catty" and say that others "monkey around" with things.

Now we come to the next question: Is a mechanistic psychology a practicable science? Obviously it is if we throw the troublesome mental factors out. What is left is taken care of in our preceding account of mechanistic biology. This gives us an "objective psychology" which is an extremely valuable department of human and animal biology. But if we stop here we leave out of our human biology the things that make humanity especially interesting to us and the most significant things that separate us from dumb brutes. If this is the best that science can do, we shall have to make the best of it. But is it?

Can we find a place for our thinking and feeling and loving and hating and ambition and disappointment and motives and ideals and aspirations and sin and repentance and spirituality in general in a rigidly mechanistic scheme of nature? If so, we must locate the machinery that performs these prodigious miracles of production. It looks like a difficult enterprise.

OUR DEFINITION OF PSYCHOLOGY

An awareness of something is a real event, and if it is a toothache it can be linked with other events in

a very natural way. These linkages can be studied scientifically in the same way as other natural relations of things. I can discover the physical causes of the pain and some of its results both on my objective behavior and on the subsequent course of my mental and moral development. This makes it possible to cultivate a real science of psychology in which the phenomena of awareness take their places along with other natural events, for the main interest of science is in the relations of things.

Psychology, as we use the word here, is the science which deals with conscious experience, with our awareness of what is going on. It includes the direct experience itself and everything else that may shed light upon that experience, the causes of it, the consequences of it, and the apparatus that is working when we have the experience.

This is a wide field which includes animal and human behavior as the organic background of mental life and as part of its instrumentation, the embryological and evolutionary development of mind and its organs, the whole physical, biological, and social environment within which all these have grown up and are now operating, and much else.

Most psychologists seem to feel that this is too big a job for them. Of course it is. No one of them can be expert in so wide a range of subjects, so the field is broken up into small farms and each man cultivates his own garden patch, the aspect of psychology for which he feels especial interest and competence. And yet no one of these cultivators can get along without some commerce with the others. The science of psychology as a whole must in the end include

the products of the labors of all of them and the young science cannot be considered as grown up until these various special disciplines are able to co-operate more efficiently than they seem to be doing now.

In the meantime let us not lose sight of the fact that our mental life is real life, part of the vital process, and open to study in all of the ways that have been mentioned. A detailed explanation of the exact mechanism employed in thinking cannot yet be given. The right answer to that question is that we do not know. Yet we all have mental experiences and by talking with each other about these and observing how we ourselves and other people behave when particular kinds of mental experience are said to be in process we arrive at a sufficiently good notion of what we mean by mind to get along with it practically. And this practical understanding is good enough for our present purpose.

The spiritual life to which we have so often referred in the preceding pages is our mental life, our conscious experience in its entirety. The word is usually used with a mystical implication of some sort; but that we want to get rid of here, for our main contention is that the spiritual life is natural life and so is open to examination by the method of natural science as soon as we learn how to do it.

UNCONSCIOUS MIND

There is so much written of late, especially in medical literature, about the unconscious mind that our position with reference to this point should be clearly defined.

Of course, if one defines mind as something else

than awareness, that is, if it is defined in objective terms, then it is easy to describe a continuous genetic series of such terms all the way from the simplest organisms—or from electrons, for that matter—up to man. So we have mind defined as behavior, as co-extensive with life, as nervous functions, as adaptiveness, and so on. Some of these kinds of mind are unconscious and some are conscious, and the relation between these two kinds of mind is still unexplained. Our problem is left just where it was when we started. The verbal trick of redefinition of mind has contributed nothing but more dialectic. What we want to understand is our own awareness of what is going on, and we do not reach a satisfactory conclusion by defining mind as something which is not aware of anything, so far as we know, and then investigating this other something. Either the awareness is there or it is not, and unconscious cerebration has nothing mental about it, though it may result in a mental process, that is, a kind of cerebration that is conscious.

OTHER PEOPLE'S MINDS

My mind I know a great deal about at first hand but not so much as I might if I paid more attention to it. To know the minds of other people is harder. We can know them only at second hand, the same as we know about muscular contraction and solar radiation and chairs and electrons and the other things that form the "objects" in our environment. If you do not see what I mean by saying that you know a chair only at second hand, read the first chapter of Bertrand Russell's *Philosophy*.

Our experience gives us evidence, adequate for

most practical purposes, for the belief that when you behave and speak as I do in certain kinds of situations your mental processes are similar to mine.

Suppose I plan to go to Boston and while I am boarding the train I see you buy a railroad ticket to Boston and board the train with me. The probability is that you are thinking of going to Boston, the same as I am. Then if you tell me that you are going to Boston, the probability that we are thinking similar thoughts is much greater. But then, of course, you may not be telling the truth. You may actually intend to go to New Haven and the whole maneuver may be a ruse to conceal your real purpose.

If it is as hard as this to find out what other men are thinking about, how much harder is it to learn about the minds of animals lower than man. The absence of a common language is the chief obstacle. But this deficiency is no bar to deceit on their part, for cunning deception is part of the normal behavior of a fox. What is he thinking about when he does it? We have no way of finding out. And the farther down the line we go from the human stock the more the behavior differs from ours and the harder it is to frame even a plausible guess about the mental processes (if any) that go with this behavior.

These are not very satisfactory ways to find out how other people and our animal companions think, but they are good enough to enable us to get along with one another in some fashion.

The examination of the human brain in normal and various abnormal conditions proves that the cerebral cortex is the organ of thinking, but it does not tell us much about the actual mechanism of think-

ing because we cannot detach ourselves from the process and then get inside to see what is going on while the apparatus is at work thinking some thoughts or other. I wonder, if one could be a magnetic field for a little while, whether it would not seem as different from the brute matter that is magnetized as our minds seem to us to be different from our physical bodies.

We can get some light on the subject by observing what is going on in consciousness while we are thinking and then trying to fit these experiences into our knowledge of the structure and physiological processes of the brain and such other parts of the body as may be participating in doing the work of consciousness.

This is the method of physiological psychology, and a very satisfactory method it is. When we have assembled all of our knowledge of anatomy, physiology, pathology, objective behavior, and introspective psychology we find that we have a very respectable body of facts about the organs of the spiritual life and how they work. This knowledge is still very fragmentary, but it is sound as far as it goes and it gives a practicable starting-point for further research. For this we give thanks and take courage.

We know what our awareness is by experiencing it. We know some of the causes that bring it about and direct its course. We know some of the results that follow from thinking and in no other way. We know that mind is always a process, not a static thing. We have no experience of mind apart from bodily organs. We know where these organs are and something about what they are. They are chiefly in the

brain, and in that superficial layer of gray matter that covers the cerebral hemispheres and is called the cerebral cortex. We can say very definitely where the apparatus of thinking is, but we are not able to tell exactly how it works.

EXPERIENCE

We have made our appeal to experience and this we have not attempted to define. But let us look into it a little further.

An earthworm is cut in two. The anterior part crawls away with apparent indifference and soon repairs the damage to its posterior end. The posterior part writhes as if in agony, but in due course also repairs the damage and develops a new head and brain. Does the earthworm have an experience, and does each of its two parts?

Does a golf ball have experience when it is hit by the driver? Perhaps. But I know of no way to find out whether the ball is aware of the experience. Certainly the objective behavior of the golf ball is different from that of a ball of clay if similarly struck. And certainly both of these behaviors are different from my own if I am similarly struck. And in the latter case I know very well that I have the experience, unless perchance the blow comes behind the ear with sufficient force to fracture the skull, in which case all my conscious experience may abruptly and permanently cease.

We may assume that the nature of the experience is dependent upon the organization of the experiencing body and that it changes with alteration of that organization. This is as true of the conscious com-

ponent of the experience as of the objectively evident components.

Adopting this general description of experience without attempting to define it more exactly, it is obvious that the experience had by an object when it reacts unconsciously is not the same thing as the experience had when the overt behavior is similar and when there is also an awareness of the experience.

If I am unconscious, a physician may cause a reflex jerk of my knee-joint by tapping the tendon. If I am conscious, the knee-jerk is apparently similar but my awareness of what is going on is added. The bodily organs which are active in the two cases are by no means the same. In the former case the spinal cord alone may be acting and the reflex may in fact be called forth in a man whose spinal cord is entirely separated from the brain by a gunshot wound. The cerebral cortex may not be activated at all. In the latter case the cortex certainly is acting. The addition of the awareness component to the first, or unconscious, experience involves a corresponding enlargement of the organic mechanism which has the experience.

Clearly when we have an experience our bodies are having the experience, and if it is a vividly conscious experience like a bee-sting or winning a hundred dollars on a horse race, the experience is a product of the action of the body and of very different parts of the body in the two cases cited. In both cases the parts which are active are different from those which perform strictly reflex acts.

Having the experience *is* the action of the body and the experience is different depending on what

parts are acting and in what way they are acting. In short, having an experience, whether consciously or unconsciously, is mechanistically determined because the experience is the natural operation of a bodily mechanism.

PSYCHOLOGY AS A NATURAL SCIENCE

We conclude that psychology, as a natural science, deals with the phenomena of awareness, with introspectively known experiences, as vital processes, that is, as integral parts of the natural unitary life of the individual. It has a legitimate interest in everything that can shed light on these aspects of our own lives and of the lives of other animals.

Our most intimately personal thoughts and feelings are hard to study by the methods ordinarily used in the physical and biological sciences. But these experiences are not isolated events; they have causes and consequences and all sorts of relations with other things and events, and these relations can be studied scientifically. The physicist studies the orbits of electrons, which he has never experienced directly, by various indirect means. The psychologist is in a much better position to study the relations of his conscious life, of which he has immediate experience, by indirect methods of a different sort.

Introspective psychology, accordingly, is a practicable science, and that too without overstepping the limits of the most rigidly defined scientific method. No appeal to non-mechanistic categories is necessary, though our popular ideas of the nature of mechanism may have to be rectified and enlarged.

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CHAPTER XVII

MENTAL DEVELOPMENT

THE PROBLEM OF PSYCHOGENESIS

MIND did begin on our planet somewhere sometime. From what we know of the early history of this satellite of the sun there was a time when no living things were possible and hence no mind as we ourselves experience it. When it did appear it was a new thing just as rivers and organisms and eyes and epic poems and rotary clubs were new. How it appeared is the problem of psychogenesis.

We can watch the drama of psychogenesis in the growing child, but only from the outside, from the gallery; we cannot get backstage to see what is going on there. For we cannot see into the baby's mind to find out what he really is experiencing during the dawn of his spiritual life. And we cannot remember far enough back to help out much with our own personal experiences.

People have always been curious to know where mind came from and what it was made out of. We have only speculative answers to these questions.

> Not in utter nakedness,
> But trailing clouds of glory do we come
> From God who is our home.

That is the poet's version. It may be true. But there are others who think that what we trail from our past are snaky skeins of degrading animal in-

stincts and bestial impulses drawn from the primordial slime out of which we emerged.

So far as we can judge from the scientific evidence, neither of these partial statements is adequate. Human nature unquestionably had an animal origin and it is still animal nature. But animal nature is not degraded nature. It has dignity and worth and it increases in competence to order self and environment as we pass from lower to higher forms.

At the transition from brute to man there was not only a tremendous forward leap in the worth and nobility of this nature, but there was a radical change in its character. That which is fit in a parasite like a tapeworm or in a ravening beast like a hyena becomes ignoble in men, even the poorest of us.

The roots of our noble as well as of our ignoble traits are clearly seen in our animal ancestry. Parental care, tender love of mates, self-sacrifice, social comity, intelligent adjustment to circumstances—these are all part of our inheritance from that same brutish ancestry which has transmitted also our selfishness, and ruthlessness, and they are by far the most significant parts of it.

Our vital problems as men differ from those of any brutes. They are problems in maintaining a proper balance between those native powers that make for self-preservation and personal aggrandizement and those which preserve and enlarge our social responsibilities and opportunities. Our success in the solution of these problems lies in the recognition of the fact that the two series of problems—those which center in self and those which reach out to others—are not mutually exclusive. They are often in conflict,

it is true, and life is at best a struggle. The measure of our success in life is determined by the outcome of this struggle. Self-sacrifice and socially minded conduct are essential to the highest perfection of the self and the largest measure of self-satisfaction and happiness. This is our humanity.

THINKING IS GOOD FOR SOMETHING

Thinking is not an expensive but useless luxury. It is a biologically adaptive function that we cannot get along without—not very far. Some animals apparently do without it, but they do not do very much compared with what an intelligent man can do.

The fact that mentality emerged from the unconscious in the course of animal evolution and especially its preservation and magnificent efflorescence in the highest animals, these bespeak for it some practical significance in the economy of animal kind. Most of us human folk make our livings by our wits, and so do our kindred among the higher animals.

The adaptive value of thinking rests on the same biological basis as the adaptive value of reflex. True, thinking is often abortive—so is reflex. In so far as thinking does not eventuate in some more efficient or satisfying kind of living it is as futile as the gyrations of a decapitated chicken.

Now, the end achieved by constructive thinking may be more efficient muscular work, as when a man who has a ton of coal to move from a deep cellar rigs up a hoist; or it may be an idea whose adaptive value comes out perhaps years later when united with other ideas in the framing of a purpose or the invention of a new machine; or it may be a hope

whose only value lies in prolonging endeavor in the face of disappointment; or it may be a new satisfaction in knowledge acquired or beauty appreciated.

These supreme mental powers are truly adaptive in the biological sense, that is, they have biological value. They have "survival value" under the conditions of our social life, where they give us the means of livelihood and the tools for enlarging the scope and the wealth of life in both its material and its spiritual aspects. And they have as much more than this as human spiritual values transcend bestial values.

RISE OF THE ORGANS OF CONSCIOUSNESS

The evidence seems perfectly clear that the organs of consciousness have arisen out of the organs of unconscious behavior in much the same way that rivers and geysers and mountains have arisen out of earth structures of other sorts and eyes and ears arose out of protoplasm that was blind and deaf. In all of these cases there has been a thoroughgoing rearrangement of the materials with corresponding changes in what the things do, how they work.

The geologists can tell us most of the steps taken in making any particular mountain range like the Blue Ridge that they have studied closely. In much the same way the comparative neurologists can tell us most of the steps by which the human cerebral cortex was built up out of nervous materials found in lower animals like fishes and frogs that have no cortex—in short, what the cortex was made out of.

I personally have spent more than twenty years on just this problem and I feel that I have some under-

standing of how the cerebral cortex, the organ of thinking, has been made out of nervous structures which apparently do not think at all, or at best very inadequately. We know this history quite as well as the geologists understand the mechanics of mountain formation.

The organs of thinking have been made out of stuff that does not think, so far as we can tell; and they have been made by as natural a process as have the organs of flying in birds been made out of organs which in the reptilian ancestors of birds were used for other purposes, that is, for crawling on their bellies.

The evidence so far available seems to indicate that as soon as the cortical mechanism begins to function in a child the spiritual life is born. It is created anew in every growing babe.

Whether we look at the newly created mechanism in the history of the race or in the development of the little child, its outstanding peculiarity is that it is aware of what it is doing. More than this, it knows what it wants to do in the future. The ability to do these things doubtless came in very gradually as human nature evolved just as it does in the growth of every child; and the human race has been improving these capacities from the dawn of mankind until now.

There is mystery here, plenty of it, for nobody understands how an awareness can be made out of something which was not aware of anything. Yet this seems to be what has actually happened. Is it any more mysterious than the fact that uranium spontaneously changes into lead with radioactive emana-

tions, or that the ability of the human retina to discriminate about two hundred spectral colors grew up out of blind protoplasm? All of these things have been brought about by natural means. There is no *more reason for calling in mystical "non-physical agencies"* in one case than in the others.

One point further. The only consciousness that we really know anything about is clearly a function of the special kind of protoplasmic organization that we see in the nervous system, and the kinds of behavior that we call intelligent and emotional conduct differ in quality and in practical efficiency in close correspondence with differences in the amount and in the internal texture of these nervous systems. The inference is, where there is no nervous system there is no consciousness—of the kind here under consideration, which is the only kind we know anything about.

Brain and mind grow up together because they belong together. Their relationship is not that of roommates, one of whom is an ugly bestial survival of man's brutish ancestry and the other a divine spirit loaned to us for a while from Olympus or Heaven, and these two unequally yoked together by arbitrary decree of Fate or Jove or Jehovah. Nor, as my brother long ago pointed out, is the human person a chimera or mythical merman or mermaid whose head is divine and whose tail is fishy.

Knowledge of the nature and mechanism of the conscious control of the personality has come slowly, and so mysticism still rules here. Most people seem to think their "spiritual life" is more or less under the control of external spirits—gods, devils, or just mischievous elves—and that the internal control is by

another spirit—soul, mind, or psyche—who lives in the body but may move out any time.

Our spiritual life is divine if you like so to dignify it. It is none the less part of our common human nature. Its roots strike down into the same natural soil as the rest of our life, and its flower and fruitage grow and expand in the same natural air and sunshine as the lilies of the field and the birds of the air. This is not to degrade man, but to dignify nature. All nature is divine by the same token.

This idea of divinity is not science. It is mysticism, poetry, theology, or something else. As a naturalist I have no quarrel with it, provided only that you do not demand of me as a naturalist that I divorce from my unitary life as I experience it any of its essential components and set them apart in a mystical realm of poesy or metaphysics where I cannot reach them to learn more about them, to learn how to enjoy them more, and to learn how to cultivate and control them better.

THE GROWTH OF MIND

Going back to origins, the simplest way is to assume that mind is coeval with matter, or perhaps antecedent to it, that there is a cosmic mind of which human minds are local manifestations. This is a very popular idea, especially among theologians. The all-pervading mind is God, and we are "partakers of the divine nature."

This, as just remarked, may be true, but we have no scientific evidence for it. There is no ground at all for assuming that inorganic mechanisms have any consciousness. We have scarcely more grounds for as-

suming that plants and the lowest animals like amebas and sponges are conscious, that is, have any awareness that is at all like our own. Somewhere between these extremes consciousness as we experience it came in. It emerged from the unconscious or from some other kind of consciousness, not from nothing.

New protoplasm is being made out of dead stuff—food and water and air—all the time in our own bodies, but always this is done by the live stuff already there. But consciousness appears anew in every child that is born, and so far as we can tell it arises from no pre-existing consciousness.

The human body is a going concern on the physiological plane before it shows any psychological activity, before it has any recognizable conscious experience. Consciousness emerges within behavior, not in order to produce behavior. Having been added to the reflexes, it controls them, guides them, supplements them. The mechanism of consciousness apparently appears and grows in efficiency by as natural a process as do the mechanisms of reflex, of tropism, or erosion. The evidence points clearly to the belief that if any one of these processes is mechanistic, they all are.

The simpler and earlier vital processes seem to be wholly unconscious. There is nothing to be gained by hypothecating an unconscious mind or by defining mind as total behavior or adjustment or by resort to any similar meaningless verbal trick to help us over the difficult places in our problem of how consciousness emerges.

The simplest kinds of awareness that we can experience in our sophisticated adult introspection seem

to be elementary emotions and simple impulses, both of them uncritical, unlocalized, and uninterpreted. I mean such feelings as well-being or *malaise* and "blind impulse" to do something; what Dr. Henry Head calls protopathic sensibility is something like this and is intimately related with these feelings.

Very likely these are the earliest conscious experiences that a baby has and perhaps the earliest kind of consciousness that any animal ever had. The mechanisms for the kinds of overt behavior that we show when we have this sort of experience are present long before we have any clear evidence that any awareness at all is present.

Even the simplest reflex pattern is directed toward the accomplishment of some definite behavior which is appropriate to the situation, or adaptive as the biologist would say. Assuming that this behavior is at the beginning entirely unconscious, it seems evident that if the animal knows what he needs, that is, if his reflex drive toward an end becomes a conscious want, his efforts in that direction will likely be stronger and more persistent. An awareness of the end toward which an impulsive drive is directed would seem to be a first step in the direction of intelligence. It is this consciousness of what we want that keeps us going after it even when the objective is not in sight and there is no specific stimulus to sustain the urge.

The first consciousness was probably predominately emotional—pain or satisfaction—but always related with some particular situation or reaction with whose consummation it is linked. The consciousness, then, arises within already established behavior

patterns to give them additional "punch" or vigor and to keep them going toward the appropriate end. It reinforces pre-existing reflexes and instincts.

The elaboration of this primitive sort of awareness leads directly to what may be described as sensori-motor thinking, that is, thinking in terms of particular concrete situations. Rational control and guidance of the first blind impulses and passions, the primitive wants and satisfactions, matures more slowly.

The transition from sensori-motor thinking to symbolic thinking and the formation of general notions or ideas with the aid of language came very gradually. Further progress in handling these symbols and devising new ones, like those of logic, higher mathematics, art, and philosophy, is still going on among our intellectuals.

These mental energies are all derived from unconscious physiological processes, the patterns which they assume in conscious experience are determined by structural arrangements of parts within the nervous fabric of the cerebral cortex, and their final result is again some change in the structural organization of the body. This change may take the form of an overt act, of spoken or written words, or of some rearrangement of nerve cells, nerve fibers, or their chemical constituents within the cortex itself. In the latter case I may say, "I have made up my mind about it," and the change in cortical "set" thus brought about persists as long as I remember or can recall the ideas which I have "made up" by the thinking process in question. The mechanics of these processes we shall have something to say about later—but

not very much in detail, for here our ignorance is more extensive than our knowledge.

ANIMALS' MINDS

Beebe describes how the army ants of the jungle build their houses. There is a massive dwelling as big as a bushel basket of very complicated construction, chambered and honeycombed with intricate passages and separate apartments for the queen, the various castes of workers, the spacious nurseries, and all the other members of an elaborate menage numbering countless thousands. It lasts the season through, skilfully designed and firmly joined to resist wind and rain. And yet every beam, rafter, doorframe, and runway is made of live ants, each clinging to its neighbors with desperate tenacity until its exhausted body is replaced by another fresh from outside forays for food and exercise. The ants not only make their house, but they are their house, for of their own living bodies they form the whole complicated dwelling.

These ants are blind and dumb, they work in utter darkness and silence. In compensation for their deficiencies there is a marvelously competent sense of smell and some other senses so unlike ours that we cannot guess how they work. They work with military precision and effectiveness. No living animal can long withstand their attack. He must escape or perish. Here is efficiency to the anth power (the pun is Mr. Beebe's), and yet little evidence of anything that we would call intelligence. The individual ant seems to do what she is built and wound up to do with the inexorable precision of the planets in their orbits. Either we have here very little mentality such as we

experience, or else a superintelligence of a sort quite incomprehensible to us motivates and guides the army as a whole without general staff or commanding officers or any other evidence of centralized control.

Our human analogies fail us. An anthropomorphic rationalization of the amazing thing is out of the question. In humility we bow our heads before a mystery that is too deep for us. The minds of the ranks of life that we are pleased to call lower—if they have any—are beyond our ken.

The evidence from behavior alone is too uncertain to guide us, as we saw in discussing Bent Russell's engine that seems to show capacity for learning by experience. In the human realm we fortunately have so highly developed a language that we can communicate some of our subjective experiences very satisfactorily. This, however, often misleads us, and as we pass down the scale to lower animals the evidence of mentality from similarities of their behavior with our own conduct when we have conscious experience becomes more and more unreliable. It is better at present to adopt an agnostic attitude than to carry hypothesis too far away from evidence.

We might put it this way. Some kinds of living bodies like plants and sponges do not show by their behavior that they have any mind, consciousness, or awareness at all. If they have any, they keep it to themselves. There is one particular living body, to wit, my own, that unquestionably is conscious. This I know at first hand, for it is my consciousness that inheres in my body. I have very good reasons for believing that other people have consciousness similar to my own because they tell me so and they act as if

they have. They do curious things like laughing at limericks and putting money in the bank, such things as I do only when I am conscious and because I am conscious.

When it comes to animals other than men the evidence is not so clear. Casual observations are of small value, for there is an inveterate and inevitable tendency to interpret the animal's behavior in terms of what we would be thinking about when we behave in that way. Indeed, this is the only way we have of forming any opinion at all about the animal's mind because my own mind is the only one that I really know anything about directly.

I do most of my thinking with my cerebral cortex. Animals which have no cortex presumably do not do this kind of thinking, and in fact their behavior gives no evidence of it. But some of my consciousness, particularly simple emotional experience, is not cortical but visceral and thalamic. Since we do not know the exact mechanisms employed here, we cannot tell how far down the animal scale this kind of mechanism and this kind of awareness are present.

We are, therefore, led to the rather unsatisfactory conclusion that we have no way of finding out what the earliest conscious processes were like, either the first to appear in animal evolution or the first to emerge in the development of every baby's mind.

When we look to the higher animals we are better off. If one fully recognizes the dangers of trying to interpret animal behavior in terms of what we experience when we behave that way and the limitations of this method, then it is possible to devise experi-

ments with animals that give real evidence—indirect, to be sure—of their mentality.

Yerkes and Köhler, among others, have done this sort of experimentation with chimpanzees, orangs, and gorillas. Their books are full of dramatic interest, and they have made it clear that it is practicable to make legitimate inferences about the intelligence of these apes which are comparable with our judgments of the mental processes of other men. Of course, the lack of common language is a very serious handicap, but this can be overcome to some extent by ingenious experimental devices.

Dogs also at times behave as if they were conscious. So do chickens, but their behavior seems more like our emotional conduct with very feeble suggestions of intelligent control of it. Now when we come to compare the brains of chickens, dogs, apes, and men we find that those parts of the brain that in men we know to be necessary organs of thinking and emotion become smaller and simpler as we go down the scale. In chickens the organs of intelligence (cerebral cortex) are very rudimentary while the organs of crude emotion (thalamus and visceral systems in general) are nearly as good as ours are.

Our own higher thinking, with the aid of language, is a function of the associational tissue of the cerebral cortex. We know that there is more than twice as much of this tissue in the most ignorant and uncultured normal man than in the most highly educated chimpanzee that ever lived. We know where it is in the brain and some of the ways in which its texture differs as seen with the microscope from the

simpler corresponding tissue in the brain of a chimpanzee.

The chimpanzee has much more of this associational tissue than a horse, a dog, or a hand-organ monkey, but not half as much as a man. What he has he uses in much the same way as we use ours, but he cannot do as many kinds of thinking with it as we can. His brain, like the rest of his body, is much like ours; but his brain differs more from ours than do his face and hands, for, as just pointed out, the ape's brain is deficient in just those associational mechanisms that make man the speaking and reasoning animal.

Our inferences from behavior and structure of the brains of these animals check up with each other pretty well at each step in the series down to the level of bird life. But they are only inferences and the mental life of these animals, if they have any at all, may be very different indeed from what we think it is. And below the birds (fishes, insects, and so on) we have very little sound basis even for inferences or speculations about their mental life. Many of them have very complex systems of sense organs which we lack entirely, and we cannot form any notion of what the world seems like to an animal with such an equipment of sense organs, or whether he senses it at all.

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CHAPTER XVIII

EMOTION

BRAINS AND VISCERA

SINCE simple emotion is perhaps the most primitive kind of consciousness that we have, it may be well to survey these experiences before going any farther. The reference here is not to our highly sophisticated sentiments and aesthetic refinements, but to crude feelings of well-being, *malaise*, or passion without intelligent appraisal or evaluation. These feelings we probably share with other animals, how far down the scale we do not know.

We paid our respects to the partnership of brains and viscera in an earlier chapter, and nothing would be gained by multiplying illustrations of the way these are intertwined. We really know more details about how the bodily organs of emotion work than we do of those of intellect.

We all know how intellect and emotion are blended in all of our thinking and how our conduct is guided now by pure reason, again by violent uncurbed passion, and at its best by a judicious blending of the two. But the motivation of our conduct comes chiefly from our feelings. Emotions supply the drive, our pains, pleasures, wants, desires, aversions, hopes, fears, and aspirations.

The original sources of this motivating power are the strongest of our animal impulses, the drives of

self-preservation, hunger, sex, and self-aggrandizement. These are not primarily functions of brains; they are the proper duties of viscera. But brains have put them under curb. They are bridled and guided by reason, foresight, and social comity. And out of this union have come the finest fruits of the spirit, "love, joy, peace, longsuffering, gentleness, goodness, faith, meekness, temperance."

We are now fortunately able to begin to untangle these intricate webs of viscera and brains. It is possible to analyze the springs of our conduct and to learn something about the apparatus of living wholesomely and happily. We begin to see that the higher life of the spirit as well as the bestial impulses of our so-called lower natures follows discoverable natural rules whose mastery may help us out in the difficult art of living well.

EMOTION: SHALL WE KILL IT OR CULTIVATE IT?

I know a woman of mature age, college bred, married, who told me that throughout her adult life she has purposefully and rather strenuously sought to bridle her emotions and to subjugate her feelings, sentiments, and passions to her reason. Indeed, she goes further and says that, since most of the mistakes and tragedies of life are directly due to the tumultuous drive of some uncontrolled emotional outburst, the emotions themselves are bad; they represent the bestial elements in our natures. They should be controlled by reason at all times and absolutely suppressed and annihilated so far as possible.

Now my friend has not been very successful in this quixotic campaign of hers. True, she has herself

well in hand; her disciplined intelligence is in the saddle and directs her life into very useful and satisfying paths; she is well balanced, efficient, sane, scholarly, and accomplished. But as for destroying her emotions, fortunately this ambition has not been realized.

She is, in fact, a very likable, hikable, campable, and livable woman, which means that she still has plenty of emotions, she still yields to the drive of impulse, she still effervesces with good humor or anger on occasion, she has keen enjoyments, fine sentiments, and healthy aspirations. She is also a devoted and affectionate wife, a good sport, and a jolly good fellow, a person one enjoys living with. Her lively emotions give her verve and her trained intelligence gives her poise..

Mark Twain reported that when he was a very young man he attended church and listened to a sermon in which the preacher told about the conscience and enlarged upon the responsibilities resting upon us by reason of our possession of this God-given faculty. Upon reflection Mark decided that his frail nature was not equal to so severe a strain, so he took his conscience down cellar and killed it with a hatchet.

To starve the emotions, to expose their tender growing members to the chill blasts of pure reason with the deliberate purpose of infanticide, to asphyxiate them with the narcotizing fumes of scientific or philosophic analysis, is to destroy not only the conscience but everything else that makes life worth living for.

My friend, to whom I have introduced you, does not know this. Reared in a rural community of primitive Methodists, religion to her means the hysteria

of the camp-meeting revivals and the hollow mockeries of a blind faith without works. She has seen the wreck of many promising young lives on the rocks of dissipation, lust, and frenzy driven by the unbridled impulses of sex, religion, or artistic self-determination uncontrolled by rational inhibition or foresight. This is altogether bad and therefore, she argues, emotion itself is altogether bad. Let us look into this a little further.

The man who loses his head in a panic of fear and so is crushed in disaster or who throws judgment to the winds while yielding to frenzied pleasure in a wild debauch is of course (for the moment, at least) a fool. But let us not too hastily assume that no emotions are good for anything.

The fact is that emotion in some form or other releases the vital energies that drive most of our worthwhile behavior. The dreary round of drab routine is followed with lagging steps. We do what we want to do with flying feet and the keener the desire the faster the pace. A danger foreseen, but not imminent, leaves us cold; we easily forget it. The evil that is upon us strikes terror into our very bowels and spurs us on to our most violent efforts. It is only when brains and viscera are out of gear that the drive of emotion heads us toward a smash, and the fault is usually with the brains.

EMOTION AND INTELLIGENCE

Our minds are not built up out of separate elements or faculties—emotions, sensations, volitions—which are somehow lying around loose and then put together much as we build a house out of bricks and

beams and nails. Whatever the mind is, it has a certain unity which depends on the vital unity within which it is generated and has its being.

Since emotion as a conscious experience and intelligence as a guide for the evaluation and control of emotional reactions are thus intimately related, it is not surprising to find that both of them are represented by definite and intimately related organs within the brain.

THE ORGANS INVOLVED

The thalamus in the middle of the brain contains the central control-works for the co-ordination of emotional reactions all over the body, and here are the organs whose activities give us our awareness that an emotional reaction is going on and our satisfaction or dissatisfaction about it.

The cortex which overlaps the thalamus is the specific organ of all our higher and more efficient thinking. It enables us to put the blind pulses of thalamic emotion in their proper places, to direct their powerful driving forces rationally, to "be angry and sin not," and to be elated without making fools of ourselves.

Cortex and thalamus are knit together by complicated systems of nerve fibers, and neither one of them ordinarily works without the participation of the other. So our feelings are intelligently appraised and all our sensations, ideas, and voluntary efforts have more or less emotional or affective coloring.

Fishes have a small thalamus and little if any recognizable cerebral cortex. Judging from the known structure of their brains, if they have any conscious life at all—and they sometimes act as if they have—

it is probably merely pulses of emotion illuminated by flashes of a rudimentary intelligence.

Birds have a much larger thalamus and a very little cerebral cortex. They act as if they were highly emotional creatures with very little practical sense, and the internal structure of their brains bears this out. Their inborn reflexes and instincts are very elaborate, perhaps more so than in mankind. These stereotyped modes of behavior often appear to be carried on in a paroxysm of emotional excitement but with very little rational control. This is the way their kinds of brains work.

When we come to the lower mammals—rats, rabbits, and the like—we find a thalamus better developed than that of birds and a much larger and more complicated cerebral cortex. And as we pass from lower to higher mammals the cortex grows apace and the evidence of intelligence in their behavior keeps the same pace.

Now as we go from the highest ape to the lowest races of men the cortex more than doubles in mass and complexity and the machinery for rational control of instinct, passion, and blind impulse is fully provided. It is only a question whether we care to take the trouble to use it.

CENTRAL AND PERIPHERAL APPARATUS OF EMOTION

The psychogalvanic reaction to which reference was made in the chapter on vital energies has been used to find out whether the body is reacting vigorously or not during strong emotion. An interesting application of this has recently been reported by Dr. Syz. His observations show that there may be very

evident changes in the body—probably chiefly in the viscera and sweat glands of the skin—when there is little or no subjective awareness of the emotion, and conversely there may be a belief in the presence of an emotion when the galvanometer shows no change in the electric potential of the body. This is a sort of imitation of emotion or illusion of an emotion.

Dr. Syz interpreted these experiments as showing the unreliability of subjective reports of emotional reactions. This is doubtless true, and they also open up the possibility of finding out some things about repressed emotion of which the person experimented upon is quite unaware.

He experimented on medical students. He read to each of them a list of fifty words indicative of a variety of situations which presumably have some emotional significance, for example, "kiss," "cheating," "prostitute," "stingy," "mother." The man experimented upon made no evident reactions to the words, but the galvanometer indicated to which of them there was a response in the form of a change in electrical potential of his body. Afterward the men were asked which of the words called forth conscious emotions.

For some of the words, like "mother," many of the students reported strong emotion, but the galvanometer indicated no bodily change whatever. In other cases, like "stingy" and "prostitute," there were many strong electric changes when the student himself reported no emotion.

The explanation of this peculiar result seems to be that the conscious emotion is more strongly "conditioned" by social convention than are the accompany-

ing visceral movements. A word like "mother" is expected to have a strong emotional appeal. The student therefore reports it. In some cases this is accompanied by strong visceral changes recorded by the galvanometer, but in a much larger number of cases the galvanometer showed no change. In the former case there was doubtless a true emotion; in the latter case the supposed emotion experienced was an auto-suggestion, a purely intellectual affair with no visceral accompaniments. There was no deceit about it. The student was telling the truth as he saw it, but he was unable to distinguish a purely cortical idea of emotion, an imitation emotion, from the genuine article with visceral reverberations, for it is probably the latter only which were recorded by the galvanometer. In the case where the word suggests an idea which is socially taboo the awareness of the emotion is suppressed, but the bodily activities show that the suppression is only at the higher conscious level. The physiological reaction is still there.

I have recounted these experiments as if it were all settled that the psychogalvanic reaction is a reliable indicator of the visceral reverberations that undoubtedly accompany many, if not all, of our genuine emotional experiences. In all fairness it should be added that the case is not so simple as this, for this reaction appears in a surprising variety of conditions, some of which have no obvious relation either with consciously experienced emotion or with visceral reverberations of the emotional type. Indeed, Carney Landis in a critical survey of this subject denies that this reaction has any significant relation with emotion at all. This seems to carry healthy

scientific skepticism rather too far. It is well established that these measurable changes in the electrical state of the body are largely due to secretion of sweat and contraction of muscles of blood vessels and hair bulbs and that these processes are regulated by the sympathetic nervous system. It is also well known that this sympathetic regulation is under more or less control from the brain and that this control is in its turn influenced by conscious experience. There is undoubtedly a cause-and-effect relation between some kinds of conscious activity and these sympathetic and visceral functions, as in the blush of shame and the cold sweat of fright. The debatable question is, just how exact is the correlation between conscious emotion and electrical changes of the skin? Certainly much more investigation is necessary before the psychogalvanic reaction can be fully trusted as an indicator of emotional or any other mental activities.

THE MENTAL PART OF EMOTION

If our knowledge of what the viscera are doing when we get angry or glad or suffer from toothache were complete in every detail—muscular spasms, ductless glands, blood vessels, sympathetic nerves, and all—we would still want to know something more before feeling fully satisfied with our scientific account of emotion. For this takes no account of the fact that I know that I am angry or happy or in pain. Does this make any difference? Dr. Watson would say "No."

To me it makes considerable difference whether it is my tooth that is aching or yours, and I believe that my personal awareness of the pain as my pain is

really significant in determining my behavior. The awareness of pain is a warning signal to fend off noxious things. To be sure, there are such signals that work quite unconsciously, particularly those which guard us against very sudden and oft-repeated dangers, like the reflex jerk of a finger from a pin-prick. These reflexes are fast and they are relatively simple. They take care of much of the ordinary routine of protecting us from injury, and sometimes they seem to work better for not being complicated by any knowledge of what is going on.

But there are many of life's emergencies and hazards that cannot be provided for biologically in this routine way. They may never have happened before or the situation may be too complex to be *provided for in advance by reflex adjustments of this* sort. Here is where consciousness comes into play. An injury or a visceral disturbance of which we are unconscious can get no relief by consciously attending to it, but if we are aware that something is wrong we may set our minds to work on the problem, and find out what to do about it.

So far as I can see there is nothing to be gained biologically by emotional awareness unless there is some intelligent awareness coupled with it. So when we say that emotion is the most primitive kind of consciousness this does not necessarily mean that it was the first to appear. Probably the dawn of intelligence came with it. But the complex mechanisms chiefly employed in vivid emotional experience are older than those that give us clear-cut understanding of just what is going on. Emotion, therefore, may be quickened in consciousness as a very keen feeling of

pain or pleasure just as soon as there is the faintest glimmer of understanding of what it is all about. These things are not separated in our own experience and probably they never were.

VISCERA ARE OLDER THAN BRAINS

It is a well-established fact that we think with our brains, and various other parts of the body more or less closely linked with the cerebral cortex. It was much earlier recognized that in emotional experience the viscera play a leading rôle. We now know that some parts of the brain are also involved in the emotions and that, broadly speaking, different parts of the brain are activated during strong emotion and hard thinking.

It is much more obvious to ordinary casual observation that the viscera are active in strong emotion than that the brain is the chief organ of thinking. So the ancients located the emotions in the bowels, courage in the heart, and so on, and we recognize the same thing when men speak of "a man of guts." We are quite correct in this so far as it goes, though of course this is not the whole of the story.

The "man of guts" stands up and takes terrible punishment and he keeps right on fighting after everybody but he knows he is whipped. We like him for it, no matter what he is fighting about, or even if it is only for the fun of it like a true-bred Irishman. But often he goes down before a weaker man with less power but more strategy behind his punch.

The man of brains is more canny. He avoids the hazard of a fight when possible and when cornered

wins out by his wits. We give him less admiration, but he is more likely to amass a fortune.

The man with both "guts" and brains is lord of creation. We must respect him. Whether we admire him depends on the quality of his brains more than the quality of his "guts." Because our visceral reactions we share with all animal kind, but our "brains," as the word is popularly used, give to our humanity its character.

For upward of a hundred million years animals have digested and assimilated food, breathed, excreted, and reproduced by visceral mechanisms of various sorts, including the ductless glands, or endocrines, and the sympathetic nervous system. Brains as organs of intentional control came very late in this history. Mechanisms of the various kinds of visceral activity were perfected aeons ago. The apparatus of thinking is a relatively modern invention and it is (we trust) still in process of improvement.

Viscera without much brains can do very useful things, and the convulsive paroxysms of fear in lowly creatures whose brains are quite insignificant serve very useful purposes. This has been brought out very clearly by Professor Piéron who says that if you tie up a crab by one claw with food in sight but just out of reach the creature will quietly starve to death. But bring up an octopus, the crab's mortal enemy, and the crab at once struggles violently in what we would call a "convulsion of fear." The fettered claw is snapped off and the crab is free to sidle off to a safer place on his nine remaining legs. Later at his leisure he repairs the damage and grows a new claw.

Whether the crab knew that he was afraid, we

cannot tell. But the emotional type of reaction was evident enough. The physiological mechanism of what we call a "fear reaction" is clearly in good working order. Reactions of this sort unquestionably arose very early in the evolution of animal behavior, and they persisted because they were useful more often than they were harmful—Darwin's principle of survival of the fittest.

They still serve the same useful purposes with us unless we "lose our heads" about them. If we had no brains this would be impossible. But having brains it behooves us to use them all the time and not let our emotions run away with us. One of the main uses of brains is to curb and guide emotion, and if they fail in this we have lost our birthright as human beings. Even a crab is a more successful organism than a fool.

A sturgeon may lay a million eggs each season. The wastage is enormous, but under natural conditions (when undisturbed by human epicures' desire for caviar) enough survive to maintain the species. This sort of visceral activity is very efficient and does quite well for sturgeons. But when the natural conditions for which this organization is adjusted are suddenly disturbed, there is nothing the sturgeons can do about it but perish. They lack the brains to make the necessary readjustment.

Men who revert to the sturgeon's level and try to get along under modern urban conditions by yielding to uncontrolled emotional drives likewise perish. They do so more slowly, and they are likely to have a much more unhappy time a-dying than do the fishes. This grows out of the fact that the human type

of organization has capacities, not only for thinking but also for feeling, which far transcend those of fishes; and the intellectual and emotional parts of our experience are so closely interwoven that they cannot be unraveled. We think while we feel and we feel while we think. An emotional upset, accordingly, is accompanied by more or less of understanding of what is going on. The intelligence stands by and appraises, perhaps in retrospect, the antics of the emotions. And if the emotions have got out of hand and have driven us into mischief, we may live over the experience and suffer remorse.

We have no evidence that a fish can do this. The advantage that we have over the fishes is twofold: First, after a few experiences of the disastrous results *of uncontrolled emotion we may learn to put the* brakes on early in the course of a passionate outburst and save ourselves much subsequent distress; and, second, some kinds of emotion are so pleasurable and so good for us that we can actively cultivate them, seek out the occasions that favor them, and pour into them all of the intellectual reinforcement and interpretation of which we are capable. So our notions of value, of what is most worth while, our ideas of truth and beauty, and our ideals of what we want to do and to be are composites of raw emotion and refined intellectuality, of viscera and brains.

But the viscera must serve the brains, not the brains the viscera.

CONTROL OF EMOTION

Emotion, then, is a product of visceral action, involuntary muscles, glandular secretion, and especi-

ally the activity of ductless glands, all interwoven with sympathetic nerves through which the brain bridles and guides the course of events. The visceral activities and the conscious experience of emotion are cross-connected both ways. Visceral action may call forth emotion and emotion may change the visceral processes profoundly. This is a circular reaction; each component may reinforce the other, on and on in a cumulative way.

In a similar way the viscera are cross-connected with the voluntary muscles of facial expression and general bodily movement by which we express our emotions to others. A violent fit of rage or a paroxysm of mirth is intensified by release of its outward expression. The most effective way to nurse one's wrath and keep it warm is to cultivate the habit of giving free rein to explosive outbursts of temper. And everybody knows (or should know) that to hold the exhibition of a passion in check is the first step in its control or complete suppression.

It is true that a vehement "Damn!" may momentarily ease the emotional strain of a pounded thumb and also that repressed emotion which is not conquered or diverted may poison the springs of joy until life is embittered. The control of which we speak is a real mastery of passion by intelligence and will-power, the domination of the thalamic brain by the cortical brain. We learn to dissemble grief and pain behind a smile, and the smile itself may go a long way to assuage the pain. To be "condemned to this fashion of the smiling face," as Stevenson puts it, is no hollow mockery; it is often our salvation.

A violent emotion may be generated by mental

effort; as the following experience illustrates. Years ago I used to amuse myself, during periods of insomnia while lying quietly in bed in the middle of the night, by conjuring up some purely imaginary situation in which I was baited by strangers or enemies (having no enemies, I could easily invent them) until I became violently angry. The passion grew from mild irritation to a paroxysm of rage. All the while I had not moved a voluntary muscle or framed a whispered word. At the climax of the fantastic extravaganza it was suddenly checked and I took stock of myself. I was all of a tremble, with labored breathing and palpitating heart, hot flushes, and a general upset of the whole sympathetic nervous system. This is not an experience to be oft repeated, for it is a dangerous indoor pastime. I soon discontinued it and do not recommend it to others. But I learned something of the mechanism of the emotions and how this mechanism can be set off by pure imagination without any direct excitation from the outside.

The converse of this is also true and practically of far greater importance. We can by conscious effort drive away an unwelcome emotion. If the emotional paroxysm is very strong, we may not succeed in doing this by a direct frontal assault upon it; but by practice we can learn how to make a flank attack, how to divert the attention from it to something else. Even the pain of a pounded thumb hurts more the harder we attend to it and less when the attention is distracted.

From this it follows that the organs of emotion are in three interconnected systems—the involuntary visceral apparatus, the nervous and muscular appa-

ratus of expression, and the central control-works of the brain. We can learn to control the muscles of expression and to show a "poker face" whatever cards we play. We can with more effort and practice get our mental processes of emotion in hand, more or less. The viscera themselves are harder to get at. They are not very educable.

The visceral reverberations of an old and long-forgotten emotional crisis may persist long after all knowledge of the experience has been banished from the mind. One may deliberately erase the memory of a disagreeable experience from the mind and yet the visceral organs do not forget it and their unconscious reactions may be influenced by it as long as we live. This is part of the organic basis of some of our personal idiosyncrasies and sometimes of those pathological complexes that are brought to light by psychoanalysis. These suppressed emotions are quite beyond our conscious control because we do not know that they are there. That is what makes them so dangerous. The great service of skilfully conducted psychoanalysis is to bring these hidden complexes out into the light where we can see them. When we know what is wrong we can do something about it. But the analysis will do no good unless the patient is willing to co-operate and play his part. No doctor can cure our ills, physical or mental. The body must cure itself and the disordered mind (which is also a disordered bodily process) must cure itself. The doctor can only help us to do it ourselves.

Most of the personal tragedies of life arise from relatively minor disorders of body or spirit. In these cases body and spirit seem to be working at cross-

purposes. The spirit may be willing but the flesh weak. Like Paul, we find a law in our members warring against the law of our minds and our anguished striving seems only to embitter the feud. Bodily ills can be treated by physical means and spiritual disorders by mental treatments; but a sound therapy of the personality as a whole can hardly be hoped for as long as we treat body and spirit separately by different specialists, each of whom pays no attention to the work of the other.

This one-sided treatment of the ills of the body and the mind is not so common as it used to be. But the average doctor, if he can find no evidence of an organic disorder still too often seems to feel that there is therefore nothing serious the matter. A case which he lightly diagnoses as "only nerves" may be a very sick patient, and he is sick all over, not in some detached psyche.

In modern culture emotion is not a by-product or a vestigial remnant of our bestial ancestry, as one recent writer maintains. Its importance and dignity are greater than ever. It is still the mainspring of conduct; but the control of that conduct is in large measure taken away from it and done by a regulator which is poorly developed in lower animals—the cerebral cortex. The demand for control of expression of crude emotion and its redirection into more refined demeanor present the major problems of our personal adjustments.

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CHAPTER XIX

INTUITION AND INSIGHT

INSTINCT AND REASON

IT USED to be taught that animal behavior is controlled by instinct and human behavior by the God-given power of reason. Instinct was regarded as the natural operation of the animal body, but reason as a divine enduement from outside the natural realm. Descartes carried this speculation to its logical conclusion and regarded all animals as unconscious automatons, or robots. Some psychologists of our generation are inclined to carry Descartes' logic a step farther and say that all men are robots too.

This illustrates the dangers arising from building up scientific generalizations by logical process from postulates that do not square with the facts.

Facts of experience common to all of us indicate very clearly that men are not unconscious automatons and that their thinking influences their behavior and the behavior influences the thinking. Facts of equally common experience, though not so easily checked up, suggest that some animals also think and that their thinking is useful to them.

Nevertheless the traditional idea just mentioned has some basis in fact. The activities of the lowest animals appear to be regulated largely by uncon-

scious tropisms, reflexes, and instincts, that is, by automatic mechanisms that are inborn and unlearned. These innate patterns of reaction are not wholly unmodifiable by personal experience, for even an ameba can learn. Whether they are aware of what they are doing when they learn we do not know. Now as we go up the animal scale these unconscious automatisms become, not less numerous and complicated, but more so. But somewhere along the line conscious control of their course comes in; reflex and instinct are gradually subordinated to intelligence.

Comparing the highest animals of today with men of today, the contrast in this respect is indeed striking. The behavior of dogs, horses, and apes is largely instinctive—that is, unlearned—while human behavior patterns are mostly acquired in the hard school of personal experience. This does not mean that we have fewer instincts than apes—James thought we have more—but that our large heritage of instinctive and impulsive reactions is masked by the fact that all of them are bridled and kept in check by intelligent regulation, more or less in different individuals and under various circumstances. This, in fact, is the chief business of intelligence of the human type.

If we knew the whole psychological history of the hundreds of thousands of years that were required to fashion civilized man out of his ancestral anthropoid, this wide gap between the mentality of apes and men would be bridged by factual knowledge. As it is we can get only imperfect fragments of the history from archaeology, the comparative psychology of retarded races, and the mental development of the human child.

REFLEX CENTERS AND CORRELATION CENTERS

Now what has all this to do with intuition? To make this plain we must return to the apparatus of reflex action and conditioned responses.

The hypothetical simple reflex is a one-to-one connection between stimulus and response like the pushbutton on my desk that calls the stenographer (the one is, to be frank, as hypothetical as the other, for my desk has no pushbuttons and my stenographer is not even a working hypothesis). But there are no such simple reflexes in the human body. The reflex centers are cross-connected in inconceivably complicated ways and every reflex movement as actually executed, even so simple a one as turning my eyes when the door opens, involves the co-operative action of many of these separate centers acting partly in unison and partly in a definite sequence. It is the complexity of these central cross-connections that makes the modification or conditioning of our native inborn reflex patterns so easy, that makes it possible to learn faster and to learn more than lower animals with smaller and simpler brains and fewer cross-connections. It also makes it very difficult to predict what will happen after any particular stimulation because of the complexity of the mechanism and our ignorance of all that is going on.

Besides these cross-connections among the primary reflex centers there are numerous higher centers in the brain that are not dominant for any particular one reflex circuit but are so connected with several such circuits that they may respond to all of them at once and in the end dominate only one of them. These are the association centers. Some are in the thalamus and some in the cerebral cortex.

Remember too that in the human brain the centers of adjustment are arranged in levels, each level being more complex than those below it and dominating their activities. The cerebral cortex is the highest member of this series. The higher levels are more plastic than the lower, that is, they are more readily modified by personal experience, they learn more quickly, they can learn more difficult things, and they remember them better.

As we pass from the lower animals toward man, the cerebral cortex gets bigger and more complicated, and the learning power improves. The memory also improves. Some of the things that the cerebral cortex of dogs and other animals of that grade does may be briefly mentioned. First off, it may hold in check some "natural" or unconditioned behavior until (consciously or unconsciously) the appropriateness of this natural reflex is tested out in view of all the conditions prevailing at the moment.

Second, at the same time that this particular natural reflex action is reported to the cortex (perhaps only in incipient form) all the other experiences of the moment are also being registered in the cortex, and the cortex as a whole acts as a "decider" whether to release the natural unconditioned reflexes or to do something else about it or perhaps to do nothing at all.

Third, the set-up of this particular dog's cortex has been determined in part by his own previous experience, what he has already learned; and when his cortex acts in response to a present series of sensory experiences all these memory vestiges of previous behavior are available and some of them are quickened

so that they share in "deciding" what is the appropriate behavior.

Stating this in dynamic terms, the present sensory stimulation has upset the equilibrium of the resting cortex and a new balance must be struck, taking into account all that is now going on outside, the "natural" or unconditioned responses to each of the sensory stimuli, and the memory vestiges of former behavior in similar situations, including the conditioned behavior, that is, what has already been learned. What the dog will do about his master's call that he now hears depends on all these things going on in his cerebral cortex and below it.

There may be some consciousness of what is going on or there may not be. So far as we can judge, much of our own unconscious behavior employs cortical and subcortical mechanisms quite as complicated as our description indicates.

UNCONSCIOUS LEARNING

The tools or instruments employed in the conditioning of behavior may now be reviewed. We start with reflexes, instincts, established habits, and organic memories. These may be all unconsciously performed or perhaps not. They are played one against another, combined and recombined in ever more complicated patterns, with shifting emphasis and the establishment of various short-cut ways to arrive at the most appropriate response in the shortest time and with minimum effort. Random trial-and-error responses are replaced by definitely learned reactions which take us directly to the solutions of problems of conduct without fumbling or uncertainty. The conditioned behav-

ior may at last be as promptly and as easily performed as were the original reflexes from which it was derived. We do many of these learned things by "second nature" quite as well as we do our primary instinctive performances, as in walking and driving motor cars, so that in adult life it is often impossible to tell whether some customary act is a true reflex or a learned habit.

All this may be done mechanically and unconsciously because the body is so constructed that changes in its internal organization follow from its own normal actions in orderly ways and in ways that will differ in each case depending on the actual experiences had.

CONSCIOUS LEARNING

Now throughout life we are producing still other changes in this organic structure by the exercise of conscious emotions, memories, and intelligent adjustments with the aid of ideas, language, imagination, and idealization. This goes far beyond the conditioning of reflexes in the sense in which Pavlov used the expression, both in the instruments employed and in the results achieved.

In attempting to interpret this consciously directed behavior some psychologists like Kempf put the emphasis on the visceral system and maintain that organic cravings originating here (hunger, sex, and the like) dominate the personality and subordinate the specific reflexes and learned behavior to these affective impulses. Others seem to believe that all human conduct and all human thinking can be reduced to combinations of simple reflexes and habits and the conditioning of these by an elaboration of Pavlov's method.

There is a basis of fact for both of these views, but neither one of them nor any combination of the two seems adequate to give a satisfactory mechanism for what we call our spiritual life. To oversimplify a problem is not the shortest way to a solution.

An instructive instance of the conditioning of the flow of saliva in dogs by Pavlov's method is given by Kleitman. Every day he put his dogs into a special cage and then gave them a dose of morphine, which causes a reflex increase of saliva. After several days they salivated as soon as they were put into the cage, even though no morphine was given, a typical conditioned reflex. This procedure was discontinued for several days during which the "learned" behavior gradually disappeared. Then dosing with morphine was resumed and the lost conditioned reflex came back in less time than it took to form the habit in the first place. If these experiments are plotted on a curve of learning the way they do in psychological laboratories when university students are trained to learn nonsense syllables, the two curves of learning, forgetting, and relearning are almost identical.

Now the dogs did not intentionally salivate when they were dosed with morphine; they were not trying to learn anything. Yet their learning curves for a purely physiological habit closely resemble those of university men who intentionally memorize lists of meaningless words. The underlying mechanisms are probably similar. Here in the case of the dogs we have physiological learning and in the case of the university men purposive learning, and both seem to work in accordance with pretty much the same rules.

We should note, however, that in the case of both

the dogs and the university men the tasks to be learned were meaningless—there was no sense to the performance, for the learners, in either case. But give a man or a dog just one experience that has meaning, that fits into a frame of previous experience and so finds the higher nerve centers already set up for an appropriate reaction, then the learning process is very different. The one new experience is immediately assimilated to old knowledge and familiar ways of behaving, and it is remembered perhaps for the rest of his life.

When I was very young I witnessed the explosion of the big flour mills in the city of Minneapolis. The huge structures of massive masonry were blown to bits like giant firecrackers. I learned then once and for always that flour dust can make a dangerously explosive mixture, though the experience was never repeated. Once was enough. This learning curve is very different from curves of physiological learning or learning nonsense. You go from no ability at all to perfect learning at one jump. The "conditioning" is done immediately because a radically different mechanism is employed. As pointed out beyond, one is oriented to the new situation immediately without fumbling. We have no evidence that very lowly animals can do this kind of learning. They lack the brains for it. So does a newborn babe.

Learning by rote, learning by trial-and-error, and learning by conditioning of reflexes are apparently fundamentally the same. In all of these cases it is probable that during the period of training some structural changes are made in the bodily mechanism which finally result in the substitution of the learned behav-

ior or new habit for the original way of reacting to the situation. We do not know exactly what these changes are, but in some of the cases we know where they are.

INSIGHT

In men and apes and probably in some other higher animals there are kinds of learning that do not fit into this scheme. Instead of frantically fumbling and clawing as hungry cats do when put into Thorndike's problem boxes, a chimpanzee when given such a problem as how to get a banana hung just out of his reach may sit quietly as if pondering for a moment, and then forthwith dart off directly to get a stick or a box or some other suitable instrument. The problem is solved, not by fumbling, but by what Köhler calls "insight."

We need not assume that Köhler's chimpanzee reasoned the thing out and formulated his conclusions in logical syllogisms. The average man would not solve the problem that way either. When a man confronted with a simple problem like this does "stop to think," the right way to do it may come to him all at once in a flash of understanding. He "sees through" the situation before he makes a move.

In the case of the man his previous experience includes many situations each of which has something in common with the present problem, and somehow the appropriate features of these experiences are assembled to give the answer to the present problem. This is clearly a cortical function, for animals without cortex do not show it, and yet the actual assembling of the related features into an impulse to go and find a stick or a box may be done wholly unconsciously. It

cannot be done without previous experience and without the cortical machinery for registering this experience in available form. The young chimpanzee cannot do this, but older and more experienced animals do it.

INTUITION

Here the ape or the man knows what to do, but he may have no understanding of how he found it out. The man may say that he does it by intuition. Thus unconscious learning plays into the hands of purposive learning.

Psychologists used to talk about apperception. When what we see has meaning it is because the perceived thing is joined to what we remember (perhaps unconsciously), to an "apperceptive mass," and then the perception becomes more than a sensing of what is here before us; it is apperceived or joined to what experience we already have. When this is done unconsciously we have no understanding of why or how we know the meaning of the thing perceived or why we adopt appropriate behavior with reference to it. This is intuition.

When we have no previous experience that fits the situation or if this experience has not been registered in available form, then we may look at the thing without seeing any sense to it. This is "at-sight" without insight.

Learning by insight, whether intuitively or by consciously directed effort, has the same adaptive value that all conscious capacities have. The ability to "see through" a situation without wasteful fumbling adds to competence as well as to speed of reaction. It requires a very complicated nervous system and it gives

us far better ability to thread our way through the intricacies of unaccustomed and often baffling situations.

INSIGHT AS ORIENTATION

Frank has pointed out that insight may be interpreted as orientation. In the trial-and-error type of learning shown by rats when they learn to run mazes and particularly when they are set to get into problem boxes of more complicated sorts, the animal has no past experience (individual or racial) to serve as background for orientation and he has a very meager equipment of cerebral cortex with which to use what experience he has. So he shows little insight. He fumbles around because that is the only way he can behave under the circumstances.

In a similar wholly unfamiliar situation an ape or a man must learn the same way. But the ape or man has wider experience and better machinery in his brain for making use of it. This past experience comes to his aid in most of his problems. He orients himself with reference to the problem, not only in terms of the present situation, but also with the help of all that he knows about it. So instead of frantically running around and blindly trying everything in sight he is likely to pause and wait for an "inspiration" to give the necessary orientation. This may come in a flash without conscious effort, or the man (not sure about the ape) may think it over systematically, make a mental analysis and "figure it out."

In both of these cases the learner orients himself with reference to the problem before a single obvious movement is made. This orienting by an internal ac-

tivity, whether conscious or unconscious, is often called implicit behavior in contrast with explicit behavior where the orientation is done by overt movements of "fumbling-and-success."

MECHANISM OF INTUITION

Insight, therefore, does not necessarily imply any highly sophisticated mental analysis, but it does imply a more or less complicated cortical apparatus of association—in other words, an appropriate mechanism. This need not be an association of ideas in the traditional psychological sense. It may be what Bertrand Russell calls an "association of bodily processes," wholly unconscious and yet quite competent to integrate the elements of behavior in new patterns. Every conditioned reflex is an example of such a process in simpler form. Cortical associations, whether resulting in awareness or not, are similar in principle but the apparatus is more complicated and the resulting behavior far more efficient.

True psychological association of ideas has probably developed out of these more primitive physiological processes, and when this stage has been reached problem-solving takes a new form. Insight of the simpler unconscious sort is probably what is meant when people say they know how to do a thing intuitively. Some kinds of problems which are too difficult to be solved in this way may yet be solved by mental associations, aided by logic, mathematics, and the other tools of "creative thinking."

Even animals as low in the scale as rats have been shown by Dr. Maier to be able to learn by the method

here termed insight, though it requires a special experimental set-up to bring this out. These rats can organize the significant parts of former isolated experiences in terms of a goal or desirable end, and they do it immediately without trial and error. This sort of behavior cannot be distinguished objectively from the simpler sorts of human reasoning. By later experiments he shows that this ability is a function of the rat's cerebral cortex and that older rats do better than young ones. As with us and Köhler's chimpanzees, this sort of insight depends on previous experience.

In the study of the learning process white rats have been used more than any other animals. Rats naturally run in rat-holes and find their way about in tortuous passages very well. So they have been trained in mazes, artificial rat-holes with many blind alleys and only one right way out to the foodbox. These mazes have been modeled after the famous Hampton Court maze, and tens of thousands of rats have been trained in this way.

When I was in England recently I thought it would be only fair to try to run that maze myself, so I went out from London to Hampton Court. As I threaded the winding pathways between the high hedges I tried to put myself into the mental attitude of a rat in a laboratory maze. But I am sure that I did not succeed very well. I knew too much about mazes to start with, and I actually succeeded in getting outwith very few wrong turns. I oriented myself mentally and did not often have to resort to trial-and-error.

But not everybody who tries this maze is so fortunate. The attendant sits on a high perch where he

can watch his victims all the time, and he told me that it not infrequently happens that people—adults as well as children—become completely disoriented and panicky. They lose their heads entirely and he has to go down and lead them out by the hand. A big cerebral cortex does us no good unless we use it.

When we see otherwise intelligent people fumbling around in situations where a little good headwork would take them through without blundering, we wonder whether our schools are really educating people or merely teaching them. I am not talking about mazes now, but ordinary problems of how to find a collar button or cook a meal.

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CHAPTER XX

LEARNING

FIXED AND MODIFIABLE BEHAVIOR

ALL protoplasm can learn, but some combinations of living stuff can learn much more readily than others and can remember what they have learned better.

Learning is a kind of behavior. The various ways that animals behave fall into two classes: first, invariable responses to stimulation like typical inborn reflexes and firmly established habits; and, second, modifiable behavior, where something new and perhaps unexpected is done. The first is a conservative type of behavior, the second a progressive type.

After suitable experience one can set up conditions where a simple reflex or habitual act will be performed whenever the appropriate stimulation is applied. Every time the proper button is pressed some special mechanism is put in operation and some particular thing is done automatically and regularly. You can predict what will happen in this particular set-up of conditions with a fair degree of probability. When a bright light is flashed into the eye the pupil contracts. When an expert typist sees the written word "habit," her fingers automatically strike the proper keys of the machine without any further attention on her part.

Both of these are examples of fixed, stabilized behavior; the nervous and muscular mechanisms em-

ployed are well known. In the first case, the reflex, the apparatus is ready to work at birth or sometime thereafter without any preliminary training. In the second case, the habit, the apparatus is not provided ready-made but it has to be made to order during a course of training. We have to learn the habit. But when it is once thoroughly learned the habit goes off as automatically as the reflex and in fact it is often impossible by simple inspection to tell, in the case of an adult man or other animal, whether a particular fixed mode of behavior is an inborn reflex or an acquired habit. The finished product is very much alike in the two cases.

There is no sharp distinction between fixed and modifiable behavior, between reflex action, learning, and habit, because these grow up together and in almost all behavior they are blended. But in most things that we do the two factors can be recognized, monotonous repetition of stereotyped routine and some degree of deviation from the standardized formula. The distinction is very important in education and the control of conduct. Our reflexes and instincts we must accept as we received them; our learning is under personal and social control. We can do more or less as we like about what we learn ourselves and what we teach our children.

Just now we are interested in the learning process and the mechanisms of habit formation, how the fixed ways of behaving that come of themselves as part of our inborn equipment are transformed into habits and other forms of learned behavior. We want to know the why and the how of that plasticity which enables the child to pass so rapidly through those

stages of infancy, bestiality, and savagery which, as James Harvey Robinson points out, form the background and starting places of all distinctively human achievements in self-culture and racial advancement. The offspring of brutes do not and cannot go through these stages and emerge from them into the competence of adult manhood with capacity for "creative thinking" because they lack those distinctively human organs of learning in the cerebral cortex which form part of our human endowment.

This cortex is immature, unfinished, at birth, and it is then incapable of performing any of the noble functions of higher learning. These come later, and so it is only later in life that constructive thinking, the distinctively human type of learning, is possible. But the underlying subcortical parts in the brainstem are in good working order long before birth, and they are capable of learning, in their own primitive way, at an early fetal stage.

PHYSIOLOGICAL AND PURPOSIVE LEARNING

Human learning may, therefore, be divided into two stages or phases. One of these is the sort which is common to all kinds of living things, the common protoplasmic learning referred to in the first paragraph. This is going on from the very beginning of the individual and it lasts throughout his lifetime.

The other kind is intelligently directed learning which is a function of the cerebral cortex. It begins some time after birth and it will go on more or less efficiently throughout life, depending on the amount and quality of cortex available and the opportunities for its exercise provided by the education of the child.

Both of these kinds of learning are done more rapidly and more easily in childhood than in old age, though intelligently directed learning in some people does not attain its maximum efficiency until middle life.

These two kinds of learning we call for short physiological learning and intelligently directed or purposive learning. This perhaps is not the most scientific way to name them, but it does bring out one feature which we wish to use here. The psychologists who do not like it can make other classifications that will suit them better.

Physiological learning is a far more primitive sort of thing than purposive learning, and the latter has evidently grown up within and out of the more primitive sort. In view of this genetic relationship it is clear that the two kinds of learning cannot be sharply separated.

Intelligently directed or purposive learning in its fully developed forms is different from physiological learning in time of appearance, in apparatus employed, in method of operation, and in the finished product. It is not so standardized or so readily predictable as physiological learning. It is illustrated by learning to read or how to use logarithms or how to manipulate the stock market.

ANIMAL AND HUMAN LEARNING

In course of the ordinary routine of their lives amebas learn, jellyfish learn, fishworms learn, monkeys learn, and children learn. In the human body we find the same kind of learning that we find in the ameba's body; but as we go up the scale of animal life new kinds of learning and new mechanisms of

learning are successively added to those already there in the lower stages. In the course of the development of the individual human body from a tiny one-celled egg up to the adult man or woman we see a similar series of progressive improvements in learning power and progressive complication of the machinery of learning.

Students of animal behavior during the last thirty years have devoted their attention chiefly to the way animals learn because this subject can easily be investigated in the laboratory and the facts discovered can be recorded in proper scientific form quantitatively in tables and graphs. In this way we have learned a great deal about how animals learn.

When these facts are matched up with what we know of the nervous systems of these animals it is found that with every improvement in the learning pattern something new is added in the nervous system with which to do the better job. We cannot go into these details here, nor can we cite any single book where the enormous literature on these subjects is satisfactorily reviewed and summarized.

We learn unconsciously not only with our brains but with our spinal cords, our sympathetic nervous systems, our muscles, and all the rest of us. In short, we learn all over because we live all over and learning is part of the vital process. But there are some parts of us that are more important in learning than other parts. These parts are the nerve centers where reflex adjustments are made and conditioning of reflexes goes on and (for intelligently directed learning) the cerebral cortex where the learning process is controlled by voluntary attention.

We have more exact knowledge of the way learning is done by rats than any other animals, not excepting children. Rats have a small but well-formed cortex, but their learning is chiefly of the physiological sort. In learning new problems like how to find their way through a maze or how to open a latch that will let them into a box containing food they show little of what we call "insight." Just what part their simple cerebral cortex does play in their learning is a very important question because here we probably have the key to the most fundamental problems of how the cortex does its supremely important work in man.

Perhaps the most important single series of observations in the whole range of animal behavior have been made by Dr. K. S. Lashley in an attempt to learn exactly how rats learn and what they learn with. So far these well-planned and very laborious experiments have raised more questions than they have answered, but the method is sound and is bringing out real facts of the utmost importance. They are too complicated to be summarized here. You will find an account of them in Lashley's book cited below and in chapters ix–xi of *Brains of Rats and Men.* The experiments are still going on in the University of Chicago where the same methods are being applied to monkeys.

ORGANS OF PURPOSIVE LEARNING

The beasts do not learn the multiplication table or how to solve cross-word puzzles because they have not the right kinds of brains for it. They cannot even try to do them or want to. The capacity to learn by conscious effort is, however, not an exclusive human

privilege. It has grown up gradually and we can see some of the stages of this growth. Chimpanzees and perhaps dogs do some of it, but they do not do it very well as compared with men. It can be done only with the cerebral cortex and some animals have no cortex at all. Insects and fishes which lack the cortex show none of it. Snakes and birds which have very little cortex do not show much of it either. They can learn things, but so far as we now know only by the physiological method. There must be a tolerably well-formed cortex before the behavior gives any evidence that intelligently directed learning can be done.

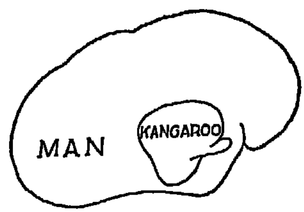

FIG. 7.—The cerebral cortex, side view, of a man and a kangaroo of about equal body weight, drawn to the same scale. (From Herrick's *Neurological Foundations of Animal Behavior*, by courtesy of Henry Holt & Co., 1924.)

In the higher animals, the mammals, learning by intelligent attention to the problem is not exactly proportional to the amount of cortex, but it can be roughly estimated from the number and complexity of the associational neurons within the cortex; and as these increase the size of the cortex increases.

The kangaroos are among the lowest mammals, with no intelligence to boast of. Figure 7 illustrates side views of the cerebral cortex of a man and a kangaroo about as big as a man, drawn to the same scale. You see here the reason why the kangaroos of Australia cannot compete with the human population in the development of that continent. The native black population of Australia, with brains more than ten

times as big as the kangaroo's, did not do much better than their animal neighbors in developing the resources of that continent. Then the white population came in.

The Caucasian brain is better organized than that of the Australian black fellow, but it is only about 12 per cent heavier. Mental capacity cannot be measured in ounces on the scales. These brains differ in their internal texture more than they do in their weight. The Australian black fellow is one of the most retarded of men, and he has the smallest brain. When put to school with white children he does very well through the primary grades, but higher learning seems beyond his capacity. He is a poor sort of a man, yet he is a real man with language, a complex social organization, very efficient weapons, and capacities for learning that no brute possesses. His deficiencies as compared with the average American are due to lack of a stimulating environment as well as to the meagerness of his brains. Even with us a few great men have set the pace which carries the rest of us along. The cerebral cortex of a chimpanzee as big as a man is intermediate between those of the kangaroo and mankind. And the learning power is similarly somewhere between. The most educated of all the apes has less than half as much cortex as any man.

We repeat, all protoplasm can learn, but not all arrangements of protoplasm can learn equally well. The kind of learning that counts for most in getting on in the world, in improving our living conditions, and in getting satisfaction out of doing it is cortical learning, consciously directed learning, activated by interest,

controlled by intelligence, and kept at it by hope of future betterment and by the pleasure we get out of the job itself.

The way in which physiological learning by conditioning of reflexes is transformed into intelligently directed learning has not been discovered, not in detail, though we see the process going on under our eyes in the case of every child. It is clear that the thing is done chiefly in the cerebral cortex and that it involves changes in the texture or internal arrangement of the web of cortical nerve cells and fibers.

LEARNING IS GROWTH

It is a curious fact that we know less about the early stages of human learning than we do about this history in some lower animals. Preyer many years ago and more recently Watson, Gesell, and a few others have studied the behavior of very young infants with scientific methods. People generally seem to object to this sort of experimenting with babies, though it does not hurt them any more than it does to try out new methods of teaching reading or arithmetic in the primary schools later in the lives of these same children. Scientific study of the behavior of the human infant has scarcely begun, and it probably will yield the biggest prizes for human biology.

Of learning and behavior in general in prenatal stages we know still less, though unquestionably there is much of interest to be found out. This field is rather inaccessible. A valuable series of observations on the prenatal behavior of rats is now being carried on at the Wistar Institute in Philadelphia, with moving-picture records of the fetal movements

at successive stages of development and anatomical studies of the bodies of the little rats at tested stages of this development. This will give us a connected account of how behavior develops from the beginning and a correlated account of the growth of the organs that are performing the movements.

Dr. Coghill, who is directing these investigations, has himself for many years been conducting a similar study of the development of the behavior of salamander tadpoles. At each stage in the development, specimens of tested physiological age are preserved and carefully studied anatomically. We now have more exact knowledge of how this creature grows during the few weeks of its life up to the time that it learns to feed and to walk than we have of the early development of the behavior of any other kind of animal. And we know many details of the changes that are taking place in the nervous and muscular systems at each change in the behavior.

Coghill's work is important because it gives the most complete account that we have of the development of a behavior pattern and of the mechanism that is behaving. He finds that learning goes on, in its early stages, by anatomical changes in the structural arrangements of parts that were already working in a different way before the new behavior was learned. The same thing probably takes place in our higher brain centers as we increase our knowledge and our skill in applying knowledge to solving new problems of conduct.

As we learn the cerebral cortex is growing, not necessarily in size, but certainly in the complexity of the internal arrangements of nerve cells and fibers. Learn-

ing can go no faster than these organic changes can be made in the texture of the body.

Some stupendous feats of learning can apparently be done in the twinkling of an eye, as when one "sees through" a difficult situation in a flash of understanding. We have already seen that this insight or intuitive learning never happens unless there is already on hand a large store of memories of previous experiences which can be linked in meaningful ways by a relatively simple act of association. By analogy of what we know is going on in the lower centers during physiological learning, it is a plausible assumption that cortical learning with "insight" is done by laying down some enduring change (perhaps in chemical structure) within some quite simple cross-connections of associational nerve fibers that link two or more already existing patterns of nervous interconnections so that these latter no longer work separately but in co-operation. This change in the "set" of cortical neurons may be done perhaps in a second, with a rearrangement of cortical habits and thought processes that may last the rest of my life. I have made a discovery or got a new idea that grips me and guides all my subsequent behavior.

CONTROL OF LEARNING

At the birth of the human child he has a considerable repertoire of reflex-behavior patterns, and his most important job for the next twenty years is to learn how to use this heritage to the best advantage. In the earlier years most of his learning takes the form of conditioning of reflexes. Then after the early habits are formed in this way his further education takes a

different direction. These habits are intelligently evaluated and controlled.

Both of these stages of postnatal learning may be systematically directed and cultivated. They are not lawless, nor are they predetermined by hereditary or other forces that act by immutable necessity. We are not puppets in the hands of Chance or Fate. The control of habit formation in its early stages must be done largely by social forces, by parents and teachers. The control in later stages becomes more and more a matter of self-direction and purposeful self-culture. The worth of the adult life depends chiefly on the ability which the individual acquires to select those values which give most efficiency and satisfaction as the controlling motives in self-development. To this extent he shapes his own destiny.

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CHAPTER XXI

ORGANS OF CONSCIOUSNESS

THINKING MACHINERY

THE educational machinery is outside of us; it is environmental. The machinery of learning is inside of us; it is part of us. So is the apparatus of every kind of conscious experience that we have. This experience, like every other vital process, is some sort of an interplay between the mechanism that has the experience, that is my body, and what is going on in the surrounding world. My consciousness, or awareness of what is going on, is a product of the activity of the internal part of this complicated apparatus of adjustment of my own behavior to the things and events of the world in which I live.

We have reviewed in considerable detail and perhaps with tedious repetition some of the characteristics of various kinds of machines. They all seem to fall into two classes: those which work unconsciously and those which work consciously. This is, of course, a very fundamental distinction. The unconscious machines show a surprising range of variety of structures and performances, from a simple crowbar used as a lever to pry with to the apparatus of the complicated reflexes of the human body.

These reflex machines that do not think are important in this connection because it seems clear that the machines that do think, like the cerebral cortex, grew up naturally out of the others. The mechanisms of

consciousness regularly make use of various kinds of apparatus that under other circumstances work quite unconsciously. Thus, thinking (a cortical function) uses the muscles of speech and of typewriting and of violin-playing and so on as integral parts of the apparatus of thinking.

The cortex may, in fact, use mechanisms which are quite outside the body in this way. The favorite violin may be an integral part of the concert artist's mental equipment quite as truly as the hands which play it and the cortex which controls these goodly instruments. Without it or with an unfamiliar instrument in his hands his power to sway a vast audience with impassioned art may be lost. His creative and interpretative skill—a cortical function—is in abeyance without this particular bit of wood in his hands. Another and perhaps better instrument will not do. I myself find that I think better with a pen in my hand. The thoughts flow more smoothly so. The pen has become a part of my thinking machinery.

OLD MIND AND NEW MIND

We have "old brains" and "new brains." Our conscious experience is also of two grades, the old mind that goes with the old brain and the new mind that goes with the new brain. The old mind is chiefly emotional and impulsive with flashes of intelligent understanding; this is the thalamic mind which we probably share with many lower animals. The new mind, or cortical mind, includes all of our higher intellectual processes, our refined sentiments, and our voluntary control of conduct.

The new brain, or cerebral cortex, does the think-

ing, not only for all of our general bodily (or somatic) activities, but also for the viscera as well. That is, the crude emotional experience related with visceral activity is interpreted and controlled by the intelligence of the cortex, and out of this partnership the higher sentiments and spiritual values emerge.

In brief, the new brain bridles and intelligently controls organic behavior of the visceral and general reflex levels and of crude emotional and impulsive mentality, and then out of the raw sense experiences and emotional pulses of these lower levels fabricates the higher life of the spirit.

The structure of the cerebral cortex is much more complicated than that of any other part of the brain, and it has not been so fully analyzed as some of the other parts. A great deal is known about it, but not enough to enable us to give a satisfactory account of how the cortex actually works during a mental process, even a simple one like seeing the sun rise or deciding whether to have pie or pudding for dessert. That the cortex does do these things, and also solve quadratic equations and design modish hats and gowns there can be no doubt. This cortex is the only anatomical organ which differs in any significant way between man and brute. All other bodily organs and all known physiological functions can be arranged in graded series with no specially significant gaps from the lowest mammals known to zoölogy to the most highly cultured men of ancient or modern times.

AWARENESS AS A BODILY FUNCTION

Our search for the apparatus of the mental or spiritual life has not been in vain. We think and feel and

will with our bodies in much the same way that we breathe with our bodies. The lungs are the specific organs of respiration. Here the air is pumped in from outside and then passed on to the blood. But this is only part of the story of respiration. Every cell in the body needs oxygen. It takes it up from the blood and passes its own wastes back into the blood again. The various tissues all over the body breathe the air that the lungs provide. Yet we call the lungs the specific organs of respiration because it is their business alone to keep up the supply of oxygen for the whole body.

So the whole body is involved in perceiving a chair, in recognizing it as my office chair, in deciding to sit down in it to dictate a letter, in the explosion of pain and resentment that follows when I am stuck by a pin carelessly left in the cushion, and in my determination to fire the office boy responsible for it. This you say is not a very high type of spirituality. Granted; but it falls within the definition of the spiritual life that we adopted when we framed our definition of psychology.

Now to continue the story, I may on reflection decide not to discharge the boy. I will forgive his heedlessness. He has some good qualities, and perhaps with forbearance and careful training he will grow up into a good man fit for a responsible position in my firm. I look forward in reverie and picture my solicitude for his welfare. I resolve to do my best by him, offering him every possible opportunity for improvement and advancement. This is better, and I settle down to my work in a glow of satisfaction.

There are bodily organs for all of these mental processes. At the surface of the body are eyes and skin and

other sense organs. Then there are nerves and muscles and endocrines and reflex centers of the brain. Finally, overtopping all of these is the cerebral cortex, and this is the core of the machine, for without this cortical apparatus none of the nobler spiritual activities could be carried on, even though all of the other organs were functioning properly. So the cerebral cortex is the specific organ of my conscious experience in much the same sense that lungs are specific organs of respiration.

The preceding account of the apparatus of the spiritual life is, of course, very incomplete. The most important items left out are the things that are quite external to my body and yet play necessary parts in the experiences narrated—the chair, the pin, the boy, and all the other environmental things to which I am reacting.

My personality is my body and everything else in our natural cosmos that affects me or to which I respond in any way. The pin is just as essential a part of the situation that we have pictured as is the skin that was pricked, the brain centers that were excited, the feeling of pain, the emotion of anger, and all the rest. The mental life as truly as the physiological life is correspondence with environment, adjustment to situations as they arise, disturbance of equilibrium, and return to some practicable balance. The elimination of any internal or external item in the total situation pictured will change the picture. A different cause is followed by a different result, that is, I do something or think something different. If the pin were not there I would not get angry. If the second stack of pancakes that I ate for breakfast were not

befuddling my perceptions I would have noticed the pin before sitting down on it, and so on.

Bodily organization, mental attitudes and habits, office furniture, pancakes, the collapse of my last business venture, the teaching I received forty years ago in Sunday school, and the fact that my great-grandfather was a Puritan—these and a million other things form the background, the setting, of that episode in my office this morning. What actually happened was the result of all these, which in the aggregate are "the cause" of the behavior.

Is it surprising that we find it difficult to unravel the threads of so intricate a pattern? The wonder is that we can discover any order at all in so complex a situation. But some of these threads of destiny are so much stronger and so much more colorful than others that we actually can follow them through and see something of meaning in the flux of daily experience.

Even the simplest sensations that we ever experience employ an extremely complex bodily mechanism. The most significant part of this apparatus is in the cerebral cortex; but the sense organs, the muscles of limbs and larynx, the viscera, the endocrine glands and sympathetic nervous system, and especially the intricate nervous machinery of reflex, instinct, and crude impulse in the brain-stem, these all have something to do with what our experiences are and how we feel about them.

We are just beginning to see what is going on in the body outside the brain during mental activity. This is the easiest part of the story to read; and the winning of this knowledge is a great advantage, because conscious processes are certainly built upon this

unconscious physiological foundation and these unconscious activities provide the raw materials out of which our thoughts and feelings are made. Not until these underlying physiological processes are well understood is there much probability that the more obscure cortical events which give the actual pattern of the conscious experience can be uncovered.

When we are thinking the whole body thinks. We think all over just as a bird flies all over and just as we are alive all over. But as wings play a necessary and special part in flying, so brains are significant in a very special way in thinking. The cerebral cortex is the specific organ of thinking in quite the same sense as wings of birds are specific organs of flight or the legs of a man are specific organs of locomotion.

The proof of this is common knowledge. We need mention only a few illustrations. Injury of the heart impairs circulation of the blood; injury of the cerebral cortex impairs thinking. Hearts of lower animals are simple, small and inefficient and as they get bigger and better in higher animals the circulation of the blood is improved; in a similar way the cerebral cortex gets larger and more complicated in higher animals and the behavior becomes more intelligent and more efficient parallel with these changes. Various drugs cause definite changes in the heart-beat; these and other drugs cause equally definite changes in mental processes. The heart may be permanently damaged by overwork and by various bacterial diseases; so may the cerebral cortex and its mental functions. We might extend this list indefinitely, but it is unnecessary.

We have only to face the evidence squarely and

without prejudice to recognize that it is as well established as anything else in biology that we think with our bodies. Mental processes are biological functions of the body in general and of the brain in particular in just the same sense that circulation of the blood is a function of the heart or breathing is a function of lungs. The evidence for this is biological evidence. It is the same kind of evidence in each of the three cases, and it is equally clear and convincing.

A great many people refuse to believe this; but most people do not know as much about brains as they do about hearts and lungs. Even psychologists often have very hazy notions of what the brain is and how it works. We are all inclined to neglect or slur over what we don't know, on the principle, I suppose, that what you don't know won't hurt you. But if you do not know that a diet deficient in vitamines will give you rickets or scurvy that may hurt you. And if the psychologist does not know that brains think his science may be rickety too.

LOCALIZATION OF FUNCTIONS

A hundred years ago two European physicians, Gall and Spurzheim, published observations on the brain, form of skull, and physiognomy of many people whose mental abilities were known, and from these facts they built up a system of charts and rules designed to enable one to forecast the character and mental traits of anybody by looking him over and feeling the bumps of his skull. Gall was, in fact, a scientific man and his contributions to knowledge about the brain were of considerable importance. But his more modern attempt to draw a horoscope and

forecast the characters and fortunes of people in general by so simple a rule was no more successful than were those of the medieval necromancers, and the practice of the system of phrenology that he founded fell into disrepute. This is not a science, but a pseudoscience, and the phrenologists who still survive are all ignorant charlatans, people to keep away from.

Gall's fundamental method was perfectly sound in principle, but he tried to work it out more than a century too early, before there were enough facts available to make safe comparisons between brain and skull, on one hand, and mental capacities on the other hand. In the light of newer knowledge Dr. Berry, of Australia, is trying it again with a better system of measurements of both body and mind. It is too early to say how successful his method is. It seems to work tolerably well in his hands.

During the hundred years since Gall vast numbers of human brains have been weighed and measured in the hope of finding some safe index of mental capacity in the size or shape of the brain. But the crude weights and measurements do not correlate well with mental ability among people of the same race or family stock. Even when different races are compared there are very few reliable racial characteristics of the brain.

The last twenty-five years, however, have seen real progress because we now have far more exact information about the functions of different parts of the brain. Our ideas of what the mind is have also changed radically during this period. Some anthropologists, like Elliot Smith and Kappers, are finding physical signs which enable them to make fairly reliable guesses about mental traits, not only from the

examination of the brain but even from study of casts of the brain taken from the skulls of prehistoric races of men of great antiquity.

The mind, as we have seen, is no longer regarded as some sort of a transcendental structure assembled from equally mystical elementary units or "faculties," like sensation, intellect, will, amativeness, and so on. Gall's attempt to localize these faculties in the brain was futile because there are no such mental faculties. The mind is the working of the body in its adjustments to things going on inside of it and outside of it. That is, it is part of this working, for not all of our adjustments are mental.

There is no mosaic pattern of cortical centers for separate mental faculties like volition or reasoning or musical appreciation or mathematical ability, each sharply defined and separate from the others, though charts purporting to show the cortical localization of these mental processes are still current.

It is true that some parts of the cerebral cortex contain mechanisms whose physiological operation is more essential for each of these mental processes than other parts. There is localization in the cortex, but it is localization of anatomical arrangements and related specific physiological functions, not of mental faculties or of anything else that can truly be called psychic. The apparatus of mind cannot be bounded by the lines that we draw (quite correctly, it may be) around cerebral regions whose physiological functions are essential for hearing or reading or writing, or speaking.

When it was discovered that the phrenological sort of localization of mental faculties is not true,

some neurologists immediately assumed that there is no localization of function in the cortex, that it is equipotential and any part of it is as good as any other part of it for any purpose, and that the efficiency of the cortex is proportional to its mass regardless of the arrangement of the parts. This extreme view is equally far from the truth. The localization is real and it is practically used by physicians in diagnosis of disease, but it is anatomical and physiological localization, not psychological.

This, again, does not mean that mental processes are homeless waifs with no corporeal abiding places. There is a physical apparatus of thinking. But the mechanism whose operation produces some particular thought, such as the purpose to push the button that calls the stenographer, is not a particular number of neurons lying in a particular spot in some convolution of the brain. The generation of the idea of calling the stenographer requires the conjoint action, not only of thousands of neurons widely distributed throughout the association areas of the cortex, but also countless peripheral activities of sense organs, muscles, blood vessels and glands—or else cortical memories of previous bodily actions involving these organs.

These functions whose totality constitutes our awareness of the idea are not disembodied, but the organs involved are not bunched at some nodal point in the brain or anywhere else. A diagram of the bodily organs actually working when I make up my mind to call the stenographer would be as complicated as the wiring chart of the telephone system of Pittsburgh.

It may be worth while to follow up this analogy with the telephone a little further. If in a strange

house you wish to call a taxicab and ask, "Where is the telephone?" you will doubtless be taken to the transmitter through which your call must go out. That is the telephone so far as your immediate interest goes. But if you find the instrument out of order and send for a mechanic, his interest covers a wider field, for the trouble may lie anywhere in the circuit. The process of telephony does not reside in the transmitter, the receiver, the bell, the line, or the switchboard, but in all of these as a working whole. So the act of thinking is a total function of a still more complicated apparatus, most of which is in the brain, but parts of which may reach out to the remotest limits of the body. Indeed, it may reach farther than this. If I am looking at a bright star and recognize it as Alpha Centauri, my thinking machinery reaches out to a distance 25 million-million miles away from me.

BIG BRAINS AND LITTLE BRAINS

A normal man has about a quart and a half of brains inside his skull. Now, if we think with our brains, one would expect that big brains will think bigger thoughts or better thoughts than little brains. Broadly speaking, this is true when we compare brains of men with those of other animals. But when the brains of different sorts of normal people are examined, after their death, the rule does not seem to hold true, for some of the heaviest brains ever examined were those of idiots. Some of us who wear very small hats get what comfort we can out of the old saying, "Little head, little wit; big head, not a bit."

The average weight of the brain of men is usually

given as about 48 ounces, or 1,360 grams, and of women, 44 ounces or 1,250 grams, with a normal variation of 35 per cent each way from this. The heaviest adult human brain that I know of weighed 2,028 grams and the lightest weighed only 200 grams. These are both pathological. Pithecanthropus, the ape-man of Java, who was almost a man, but not quite, had an estimated brain weight of about 900 grams and the chimpanzee a brain which weighs 400 grams.

Any brain from a modern man of the white race that weighs much less than 1,000 grams is abnormal and the owner of that brain was feeble-minded. Normal mentality cannot be carried on with so small a thinking machine. But it is surprising with how little brains some people can manage to keep alive, if somebody else will do their thinking for them. There is an account of one woman who died at forty-one years of age and whose brain weighed only 289 grams, or about 10 ounces. It is reported that she sang and talked fluently, but there is no record that she ever said anything very important.

Clearly, then, there is some relation between amount of brains and intelligence. It is true that more depends on the texture or quality of the brains than on their bulk, yet there is a certain minimum amount below which normal mental capacity is never found. And within the wide range of normal variation in brain size there are some indications that on the average the more competent people have larger brains. This statement must not be applied to any individual case, for there are many other things besides size that have to be taken into account. It is true only of averages of large numbers of people of the same race.

A striking illustration of the correlation of mental competence with size of brain is given by Professor Wingate Todd, who since 1913 has measured the volume of the brain in many hundreds of the unfortunates who finish their days in destitution as wards of the public charities. His account is so graphic that, with Dr. Todd's permission, I quote it in full.

The average brain volume of the adult white man is generally accepted as about 1,500 cc, perhaps a few cc more, probably no less. Among the diners here to-night, who may be classed as highly intellectual, the mean value is probably 1,550 cc. The average among Cleveland's social ineffectives from 1913 to 1917 was quite constantly within 10 cc of 1,480 cc. This difference made no impression upon us until in 1918 a strange thing happened. Our average fell to 1,410 cc. Now during that year none but the veriest fool was left destitute: the others were all in the army or earning good wages in civilian life. Still we were not stirred to attention. But in 1919 when, after the armistice, industrial stagnation set in and threw out of work many who had recently found jobs; and when, moreover, the disbanding army disgorged a glut of men upon a society which could not immediately absorb them, the average brain volume of our social failures rose to 1,520 cc. That looked serious to us and with great interest we read the prognosis of bankers and captains of industry regarding the future. According to prediction the situation improved in 1920 and our mean brain volume sank once more to near the prewar level. But the feeling of satisfaction soon gave place to apprehension, for a second and much worse industrial depression set in, distress growing steadily more acute during the months of 1921. Then indeed we watched our steadily mounting average volume. Day by day, like obscene demons from the pit itself, we chalked up the rising score until it reached the appalling level of 1,550 cc. Here was a

new class of men entering our portals and they came by a different route. Here were the men who could think for themselves, who knew and resented their fate. The pneumonia of the shiftless, the tuberculosis of the overwearied struggler, the heart disease of the adventurer no longer acted alone as our receiving agents. Instead men shot themselves, or each other, threw themselves into the lake; poisoned themselves with morphine or raisin jack; perished of cold, listlessly lost in despair. All through that year and into the early months of 1922 the steady shuffle of feet on the doorstep of the Associated Charities swelled its monotonous dirge. Agitation was rife. Russia and Germany were pointed out as members of the community of nations who had passed that way before. And then, suddenly as it had begun, while yet the Charities were deluged with the throng, these expectant ghouls in anatomy saw the barometer of brain volume begin to fall, steadily, steadily down. Relief had come: though it was not apparent to the city we knew the end was in sight. Hope was restored again in those whose nervous system had been shattered by defeat. Never again have we seen the like. Slight fluctuations from year to year and an average somewhat above the pre-war mean have been our lot but never that alarming rise which we experienced in the year of intense depression.

Now these things sent us back to examine our data anew and we soon found that of two heads of the same size one might have as much as 200 cc of brain more than the other. It was not that we got larger heads in 1919 and 1921, but we got bigger brains among our social ineffectives.

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CHAPTER XXII

THE THINKING PROCESS

THINKING AND SENSORY PATTERNS

THE cerebral cortex cannot do any mental work except with materials which have been supplied to it from lower parts of the brain in the form of incoming nervous impulses or with memory vestiges of previous excitations of that sort. The lower centers of the brain-stem also ordinarily become active only as they are played upon by outlying sense-organs. This is the physiological statement.

We express the same thing in psychological terms by saying that we have nothing in our minds, no content of consciousness, that is not derived from experience, and our experiences in last analysis are things that have happened to us. Crude sensory experiences are, however, worked over consciously into new patterns, as in imagination and invention, so that many of our more sophisticated experiences are really generated within the cortex. But never without something in memory or in present sensory excitation to work on.

It is not generally recognized that the stream of nervous impulses between sense-organs and brain is not one-way traffic. Most of these nervous impulses are directed inward toward the brain, but there is a respectable amount of transmission in the reverse direction.

This is most evident in the eye, for the optic nerve contains a very large number of nerve fibers which conduct from brain to retina. Just what the effect of these outgoing nervous currents upon the retina may be is not very clear. In some fishes they have been shown to cause changes in the length of rods and cones and in the retinal pigment, and probably in our own eyes they have some effect to alter the sensitivity of the retina to light. Besides these outgoing fibers in the optic nerve there are fibers in other nerves that activate the accessory organs of vision, those, for instance, that change the size of the pupil and the focus of the eye.

Most sense organs are under some sort of central control of this sort, and inside the brain there are similar nervous connections which may activate or sensitize the lower sensory centers.

Conscious attention to anything going on outside implies an organic tension within the nervous system and this tension may extend outward even to the sense-organ itself so that the sense of sight, for instance, becomes more acute when we are straining the eyes to read a distant street-sign. The eye serves the mind and the mind, in turn, serves the eye.

The muscles have a sensory nerve supply which is as important as their motor nerve supply. The "muscular branch" of a nerve, say to the biceps, has about one-third as many sensory fibers as motor fibers, so that every change in the contraction of the muscle is directly reported back to the brain. These muscular and similar "intimate" sensations rarely are clearly recognized, yet they play a tremendously important part as the organic background of our conscious atti-

tudes and reactions. They are essential parts of our thinking machinery.

THINKING AND MOTOR PATTERNS

The part that muscular movement plays in thinking has received a great deal of attention of late. The central and peripheral apparatus of speech is naturally of special interest in this connection. The way this works out may be illustrated by some very commonplace experiences.

This morning while I was shaving I looked at my watch. I really wanted to know what time it was, for a nine o'clock engagement was imminent. But my attention was on the problem of the moment—how to get rid of yesterday's growth of beard without undue damage to the cuticle—and past experience has impressed upon my shaving habits the importance of attending strictly to the business in hand.

As I glanced at my watch I formulated the unspoken words, "eight o'clock." Whether my lips moved I do not know. Very likely. There was undoubtedly an innervation of all of the nervous and muscular organs commonly used in the utterance of those two words. Some of the muscles of the larynx probably came to full contraction with a tightening of the throat. Others, perhaps those of the lips, began to contract but got only as far as the beginning of the full movement. Still others may have been innervated but not vigorously enough even to start a movement. Upon later repeating the performance, this is my impression of what happened.

But I immediately forgot what time it was. There was a moment of mental confusion. I stopped shav-

ing and tried to remember, for I needed to know. I was about to look again at the watch when I found myself repeating the unspoken words, "eight o'clock."

The higher cortical mechanism of thinking had failed to come across with the idea and reformulate a memory of the actual time, an idea which for a fleeting moment was doubtless present in my mind when I first looked at the watch. They failed to do this in spite of a conscious effort on my part to recall it.

Meanwhile, the lower motor apparatus, nervous and muscular, was reactivated by these efforts in a way that I do not understand, for I was wholly unaware of it, and this motor apparatus came back with a repetition of the incipient utterance in a form as clear and brilliantly perceived as if somebody else had spoken the words. I did not remember the time, but I remembered the words and they told me the time. An appreciable interval lay between the recall of the words and my understanding that this was what I wanted to know.

The motor centers of my brain retained the impress of the pattern of their recent performance more clearly than did the higher association centers which built up the idea, "eight o'clock," in the first place; and they retained it in more readily available form. When I began to try to remember the time, various exploratory innervations shot through the association pathways of the cortex as I felt out first one clue then another in the attempt to recall the missing idea of the time. The particular combination of nerve cells and fibers in the association centers whose activity produced the idea in the first place was refractory; it

did not immediately respond with a repetition of the act.

But the motor centers had been left in a more favorable set, so that when some unknown pushbutton was pressed by the exploratory innervations during my conscious search for associational clues to the missing idea, then the motor mechanisms went off according to the pattern of the set-up of the recently enacted verbal formulation and the words came to mind, apparently "of themselves" without conscious direction. In short, I remembered the words, not the idea, and then the words called back the idea.

For a rude comparison take the case of an alarm clock that has been wound and set for eight o'clock and then the hand of the alarm dial broken. In the mean time I have forgotten for what time I set it and I want to know. The alarm was set all right and it will go off at the time for which it was set, that is, when the hour hand reaches that place on the dial and releases a trigger, just as my neuro-muscular apparatus was set to say "eight o'clock" and can go off again and repeat the appropriate muscular movements whenever the proper trigger is pulled. I can find out for what hour the alarm of my clock was set by an experiment. I can slowly turn the hands of the time dial and so explore the whole twelve-hour period. When the hour hand reaches eight o'clock the alarm responds and tells me what I had forgotten. This experiment is a simplified diagram of what I did when I consciously explored the field of my cortical associations in the search for the trigger that would release the mechanism for recalling the idea of the time. I did

not find this trigger, but I pressed another that gave me the words which in turn told me the time.

Here is another and even more striking illustration of the curious ways in which our brains work. My mother has for many years been very deaf. It is possible to make her hear by shouting very loudly right in her ear. When my wife wants to tell her something she is apt to go through an amusing series of preliminary stages. While crossing the room to reach my mother's ear she will speak the words in an ordinary tone of voice as a sort of preliminary warming-up of the speech mechanisms for the more severe enterprise of repeating them in the deaf ear with her utmost vocal effort.

Doubtless the words were first formulated with only incipient vocalization, as we all habitually do in ordinary conversation. Then in preparation for the supreme effort they were reformulated in ordinary tones, a futile gesture of no use to anybody except the speaker herself. My wife, so far as I know, is quite unaware that she does this, and she will probably be greatly surprised and perhaps incredulous if she ever reads this account of her speech habits.

These motor innervations play a much larger part in our ordinary thinking than was formerly supposed. Watson in particular has done a good service in calling attention to them. They are evidently very important in the simpler thought processes which grow out of the still simpler "sensori-motor thinking," where the idea comes to mind immediately following some sensory experience.

It is evident that the stimulation of the eye by the sight of the watch dial and the activation of the visual

sensory centers of the brain are necessary parts of the process. It is not so generally recognized that some sort of a motor response or the innervations which form the preliminary stages of such a response are equally indispensable in this sort of thinking. The response here plays much the same kind of a part that the visceral reactions do in emotional experience which we have already considered.

Having simple ideas and having simple emotions are both circular reactions. Something happens in the outlying parts of the body. This is reported back to the brain through the nerves, and the brain sets in action the appropriate nervous, muscular, and glandular organs to make the customary proper adjustment to what has happened. An accidental glimpse of the watch lying on my dressing table may cause a reflex movement of the eyes so that they focus upon it. This calls up an idea in the form of a question, "What time is it?" Attention is now given to the watch dial and then the response follows in the form of words, "eight o'clock." This motor mechanism in turn reacts upon the organs in the brain that make ideas and it forms part of the machinery of vivifying and stabilizing the idea. In memory this process is repeated and the motor apparatus, in the absence of the initial sensory stimulation, may serve as curtain-raiser for the next scene of our dramatic career, in this case for remembering that it is eight o'clock and that I must finish dressing and breakfast in time for a nine o'clock lecture.

This is an incomplete, indeed a decidedly sloppy account of what has happened. Much of it is theoretical and of doubtful authenticity. But it is evident

that parts of this complicated series of events are conscious experiences; of other parts we are wholly unaware. The conscious and the unconscious, sensory stimulations, muscular responses, visceral reactions, complex cerebral activities, reflexes, associations, unconscious and conscious memories—these and much else besides are all going on during the simplest conscious act like seeing what time it is. Some of these things we understand pretty well and we know the mechanisms that do them, but some of them are still very mysterious. They all seem jumbled together, but in reality they are not scrambled promiscuously. Everything goes on in order and each phase of the process is the cause of the next phase, whether that phase is conscious or unconscious or a mixture of the two.

MOTOR PATTERNS ARE NOT THOUGHTS

Motor patterns play so large a part in our ordinary thought processes because they are equally fundamental in the more primitive reflex behavior out of which the thinking process has emerged. For every reflex and habitual act there is a neuro-muscular organization ready-made and all set ready to be touched off when the appropriate pushbutton is pressed. These are parts of the permanent structural organization of the body just as the mechanism that rings the bell is part of an alarm clock. And they are always wound up and ready to go off. In the reflex, the conditioned reflex, or the habit these motor mechanisms are so geared in with the sensory centers of the brain or with higher correlation centers that they are released with the execution of some particular kind of behavior whenever some particular experience is had.

The soldier has learned to come to attention and salute in the presence of an officer, so that the sight of the insignia of rank releases this motor mechanism automatically. Not until this automatism has been carried through can he receive a command or deliver a message.

Our language habits have been built up in this way. The child learns to speak largely by a process of conditioning of reflexes. These motor patterns of speech are the most important tools of thought that we have. But speaking is not thinking. Thoughts are the most valuable commodities on the market, and talk is the cheapest.

Because during thinking we can observe the muscular and other peripheral parts of the complicated series of events more easily than the central or cortical parts, some psychologists are inclined to pay little attention to the central processes and to regard the muscular movement as the most significant thing in the thought process. To try to find out the things that we most want to know about human behavior by the study of laryngeal reflexes or other motor patterns alone will take us about as far as an engineer would get in an understanding of the principles of design of an airplane by observing the movements of the propeller and the rudders. We need to know what is going on inside.

One thing is clear. The whole series of central and peripheral activities that go on during thinking hangs together. The act of thinking even the simplest thought that we can think is no simple function of some little spot in some convolution of the brain. There is no single brain center for seeing what time it

is or for reading or for enjoying music or for solving mathematical problems or for making moral precepts or for volition or for any other mental act whatsoever. Each of these is an extremely complicated process with unconscious and conscious components interlocked and interrelated in ways that we are just beginning to understand.

The unconscious parts of the process can go on without the conscious parts, but the conscious parts cannot go on without the unconscious. For the mechanisms of consciousness are superposed upon the reflex apparatus and there is no way for sensory stimuli to get through to the cerebral cortex at all except by way of the lower reflex centers. These lower centers are activated and in process of reaction before the cortex even begins to act. What comes into the cortex are not raw sensory excitations from eyes and ears and so on, but organized behavior patterns as going concerns. The lower centers are actually doing something in response to sensory stimulation before the cortex can be affected at all. The results of this preliminary or incipient reflex activity are passed on to the cortex which sizes up the total situation and strikes a balance between the various conflicting impulses of the lower centers. It may check some of them and reinforce others, or it may check them all and start some entirely different response to the situation.

THE OUTPUT OF THE CEREBRAL MACHINE

Our brains take care of our ordinary reflex adjustments to what is going on around; they constantly pour into all the body muscles a stream of nervous impulses that keep them more or less keyed up or "in

tone," that is, ready for action like a foot-racer "all set" for the starter's pistol; they provide automatic control works that arrange the reflexes in appropriate sequence and combination; they contain elaborate and extremely sensitive apparatus for learning, for profiting by experience and modifying behavior in the light of advantage or disaster resulting from previous experiments in the adventure of life; they remember what they have learned; they recombine present experiences and memories of old ones in new patterns that have never been experienced, that is, they have imagination and invention; they devise symbols for various relations of things which are uniformly experienced and so build up ideas and concepts—language, musical notation, mathematical formulas, laws of nature, and so on; and, finally, they generate purposes, ideals of conduct and character, and they voluntarily strive to enlarge and enrich our experience, our knowledge, and our competence to make a better living and to lead a better life.

This is only a partial list, but these are fair samples of what brains are and what they are for. And this is not a theoretic analysis. It has factual basis.

If any reader began this chapter with the expectation that he would find here a clear explanation of the bodily mechanisms of thinking, imagination, emotion, volition, and appreciation and of the way in which spiritual forces activate our mortal bodies, he is already disappointed. I am sorry. But I would be much more sorry if any reader were to finish this chapter feeling that, because we have not yet found satisfactory answers to his questions, science is bankrupt and no hope is to be expected from this quarter.

Some of us who are occupying ourselves with investigation of these questions and who have seen the notable advances of the last twenty-five years feel that we are at the threshold of a new era. We are facing forward toward more fruitful research, not backward toward outworn dogmas; and we look forward in the hope and confident expectation that the problems of mind and the problems of matter are not insoluble questions, that they must be solved together not separately, and that the scientific method will in due course open up the right road to travel toward this consummation.

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CHAPTER XXIII

MENTAL BALANCE

PROBLEM-SOLVING

CORTICAL resolution of behavior problems may take a long time, for the cortex has the power to hold all reactions in check and release motor responses when it gets ready. It not only balances one set of simpler reflex impulses over against another, but it brings in memories of past experiences of similar sort and these too enter into the trial balance of the problem of the moment, so that we act in view of all past experience as well as of the present situation. Problem-solving is a typical cortical function.

But problem-solving is not exclusively a cortical function or a conscious function. Many animals that have no cerebral cortex at all solve simple problems of behavior; so do some ordinary machines. Here is a problem of distributing a page of "dead matter" type which the printer wants to get back, each "sort" into its proper box. He may do it by hand or he may use a type-distributing machine which sorts out all the *a*'s into one box, and so on. The machine does this perfectly while the printer goes on about his other business and solves other problems of typography or whatnot which are too difficult for the machine.

There is in the Massachusetts Institute of Technology a machine, a glorified adding machine, that

will solve most mathematical problems involving the calculus, any second-order differential equation. In a few minutes this mindless machine will solve problems that would require many weeks for the expertly trained mathematical mind to solve; indeed, it will solve some kinds of problems that baffle completely the most competent mathematicians (for a description and picture of this machine see the *Literary Digest* for December 17, 1927).

This machine was made and operated by clever men. The computing machine that solves mathematical problems which its inventor himself cannot solve was nevertheless designed by an intelligence which knew what it wanted to make. But there are many natural machines that do still more wonderful things without, so far as we can see, any intelligence at any stage of the process. These natural machines may also solve problems. "Water seeks its level," which is another way of saying that the movements of water conform with the laws of gravitation. If the original channel is blocked, it "seeks" another way out and rises behind the obstruction until it finds the next lowest barrier, over which it pours on its troubled way to the sea.

An ameba solves problems. If it brushes against another tiny animalcule that is good for food, it grasps it and tries to hold on to it until it can swallow it in its curious ameboid fashion. But the animalcule struggles and breaks away. The ameba follows, now touching it again and now far behind (as the ameba measures distance). Such a chase has been watched for twenty minutes before the ameba outmaneuvers the quarry and then settles down to digest its meal in

quiet. This is as real a problem as that of the human hunter who stalks a deer or of a railroad magnate who wins control of a competing line. We have no assurance that the ameba knows anything about it.

We know the mechanisms of problem-solving by inorganic machines pretty well. We have considerable knowledge of the means employed when the ameba solves its problems. We call them "tropisms" and the like.

Many problems of human conduct are solved quite as unconsciously as are those done by the computing machine or the ameba. Fortunately we do not have to stop to think to dodge a flying brick or to use a fork instead of knife in eating pie. Many surprisingly complicated feats can be performed by what goes under the name of "unconscious cerebration."

I have often recounted the tale of an experience I had during the first year of my college teaching. I was trying to teach physics, of which I knew appallingly little, to a class of Juniors. We were using a text that I had never seen before and it proved to be full of difficult mathematical problems. Now, since I knew even less of mathematics than of physics, the outlook for my complacency was rather bad; for of course I wanted to impress the class, some of whom were older than I was, with my competence and dignity. But since they were at that time engaged in the study of calculus, I cherished the fond hope that among us we might win through without too-embarrassing exposure of my own ignorance.

All went well for a time, for of course I always worked out the problems before assigning them to the class and if one proved too refractory I graciously

allowed them to omit that one. But one day, in the press of other duties, I had not found time to work out my problems in advance. Instead of excusing them from any problems for that day, as a wiser man would have done, I rashly assigned a half-dozen at random. That evening when I sat down to work them out they all came easily but one. I worked at it until nearly morning, but finally had to appear before the class without the solution. The class should have had it, for all were fresh from their higher mathematics and not all of them were as mathematically stupid as I was.

Yes, they had all the problems except the critical one, and nobody had that. I reassigned it and spent another long night of anxious toil upon it, again without success. And again the next day the problem was reassigned to the class.

I was too young to humble my pride by going to my good friend, the venerable professor of mathematics, and asking for his help. The farce was rapidly becoming a tragedy, for I was losing more sleep than I could afford. After the third reassignment I went to bed about midnight exhausted and disheartened. Six hours of refreshing and dreamless sleep and I awoke suddenly with the solution in my mind as clear as crystal. It was surprisingly simple, as I triumphantly demonstrated to the class three hours later.

How did I do it? I do not know. Unconscious cerebration. How did I learn to dodge a flying brickbat? I do not know that either. Reflex. How does the ameba stalk its prey and succeed in catching smaller "bugs"? Who knows? Tropism. These words take us only a short distance toward the answers.

When I solve a problem by long-sustained conscious attention to it and hard intellectual work upon it, I am unquestionably using a large repertoire of unconscious mechanisms of the same general types as those just mentioned. And I am using in addition a mechanism in my cerebral cortex which is different from all of these.

We know something of the mechanism of the computing machine, something of the mechanism of tropism, of reflex, of unconscious cerebration, and of consciousness. We do not know all about any of these and we know less about the later members of the series than the first.

We put the type-distributing machine and the computing machine in one class and the physiological machines in another class and the conscious machines in a third class because there are very evident differences between them. One of these differences is that more is known about the details of the first class than of the second and more of the second than of the third. That is, somebody knows more. But I personally know more about the apparatus of reflex than about the computing machine. Indeed, I know more about the mechanism of consciousness than I do about that marvelous piece of dead mechanism. Few people have any conception of how much is actually known about living mechanisms. If they knew more about it perhaps they would be no more inclined to invoke magical explanations for thinking than for the computing machine.

In our series of problem-solving machines it may be objected that we are assembling things that are so unlike that our analogies are misleading. Granted

that they are very dissimilar and that we understand the simpler mechanisms much better than the more complicated ones. But let us look for a moment at their similarities, not the differences, and we shall see that there is more than analogy here. It is a genetic series. For the higher members have undoubtedly sprung from the same sorts of things as we see in the lower, and we can follow some of the steps in this evolutionary sequence even though we cannot give a full scientific account of them.

There are gaps in our knowledge of this series, but it has all the earmarks of being as true a genetic series as is the rise of the horse from an ancestral form which was not a horse. It is hard to break away from the habit, thousands of years old, of invoking magic to account for consciousness. The more recent habit of conjuring up a mythical unconscious mind does not help us any to get over the hurdles of those unconscious creative processes to which we have referred.

We used the analogy of a wound-up alarm clock in our account of the storage of memory vestiges. But this analogy breaks down at a critical point, for our memories are not kept in reserve in any such static fashion. Truly they are structural alterations of brain tissue. But they are not passive structures. They may be pictured as alterations of tension and these tensions are able to react one with another at subconscious (that is, unconscious) levels and to recombine in new patterns, all without any awareness on our part of what is going on. This is why new ideas and all sorts of "intuitive" impulses come to us ready formed out of the unconscious, why we have flashes of insight that seem to have no parentage in our con-

scious experience. This is not unconscious mind or unconscious thinking; it is unconscious cerebration, or, as MacFee Campbell expresses it, "the living residue of past experience." This residue gives us new mental experience only when it becomes mental, that is, when we become aware of it.

CORTICAL EQUILIBRIUM

Let us recall that the work of machines in general results from some disturbance of a resting equilibrium and the machine continues to work until some stable equilibrium is restored. Steam pressure generated in a boiler disturbs the equilibrium and the engine continues to run until the fire goes out and the pressure drops.

This principle applies in all machines that we know anything about, and with special significance in the living machines. A physiological gradient in a plant or an animal body results from the local disturbance of the vital equilibrium of the resting condition, and it continues until a new equilibrium is established —until the stimulating cause is removed and the body stops moving, or the growing point stops growing, or whatever it is that is active comes to rest.

A nervous excitation is an upset of the *status quo ante*, of the resting state that was there before the body was stimulated. Nervous conduction is a similar disturbance of the equilibrium of the resting nerve fiber. A single pulse of transmission can continue for only a very short time before this change is complete; the fiber is exhausted. After a few thousandths of a second's rest the former balance is restored and the fiber is again excitable.

A powder fuse is in stable equilibrium until it is lit. The burning is an upset of this equilibrium which is transmitted to the charge which is exploded in this way. Then the thing comes to equilibrium again and the process cannot be repeated until a new fuse is laid and a new charge of powder is put in place. In the nervous system the fuse is automatically relaid, for the nerve fiber returns to the excitable condition in a very short time. Part of its substance was consumed and part was rearranged during the conduction of the nervous impulse, and during the short period of rest the consumed substance is replaced, the former arrangement is restored, and the fiber is again excitable.

Now turning from the nerve fibers to the nerve centers, these are in particularly unstable equilibrium. In rest they are relatively inactive. A very slight stimulation is often sufficient to pull the trigger and fire them off. Then something happens in some remote part of the body with which this particular center is connected.

I step on a tack and immediately pull my foot away and perhaps say things. I glimpse a pretty face. If rude, I may turn and watch it, and next year I may marry its owner. Having pulled the tack out of my foot and expressed the sentiments of my mind about it, or having safely married the girl of my choice, I settle down to equilibrium again and things go on in humdrum fashion.

Of all the nerve centers, the cerebral cortex is the most unstable and the most easily upset. Its structure is so very intricate that it may be partially upset or the local equilibrium disturbed in a great variety of ways. If totally upset everywhere, we have a general

maniacal outburst or a convulsion. Normally the upset is mild and local, and this may happen in so many different ways that it is harder to predict what will happen after cortical excitation than when one of the lower centers is affected.

A bright light thrown into the eye will contract the pupil. It always does with normal people. This is not a cortical reaction. But a fleeting glimpse of a wisp of yellow hair may change the whole course of a young man's life and neither he nor anybody else can tell how it does it or foresee what will happen. The last case is as mechanical as the first, but we do not know the mechanism as well and there are too many variables to make analysis easy. It all depends on how the cortical mechanism was set up at the moment. And this depends on numberless previous experiences as well as upon inherited disposition.

THE EQUILIBRIUM THEORY OF CONSCIOUSNESS

When we examine the act of thinking as a process introspectively experienced, we find that it has some points of similarity with the operations of all the machines of which we have been speaking. These mechanical processes were all found to result from disturbances of equilibrium and to be essentially measures adapted to restore the equilibrium.

The same proves to be true of all mental acts as experienced in consciousness. The resting consciousness, the vacant mind, is in equilibrium. Something happens inside or outside the body which quickens the mind, awakens consciousness, or starts a train of thought. The process continues until fatigue, the satisfaction of a curiosity, the solution of a problem, or

something else brings it to a close because mental equilibrium has been restored.

This is not a new idea. Many years ago my brother, the late C. L. Herrick, outlined it under the title, "The Equilibrium Theory of Consciousness," and other psychologists and philosophers have presented it in various guises. It has recently been rediscovered by R. B. Raup who has written a book about it which he entitles, *Complacency, the Foundation of Human Behavior.*

Professor Herrick approached the problem from the neurological side and said: "The theory of consciousness which seems best to conform to the conditions of brain structure and its observed unity is that each conscious state is an expression of the total equilibrium of the conscious mechanism, and that intercurrent stimuli are continually shifting the equilibrium from one to another class of activities." And in another place: "The transmission of nervous force does not produce a higher force; but the peculiar interference or increase of tension of nerve forces in antagonistic equilibrium does."

Dr. Raup goes at it from the psychological side. He recounts an experience in a restaurant when upon leaving he found that a stranger had taken his hat and left in its place an outworn and shabby wreck. He pictures his dismay and the general disturbance of his mental poise; then his return to complacency, that is, to equilibrium, when the stranger hurries in to restore the hat, with many apologies.

This is the starting-point of his argument; and then he takes us back to the flowing movements of an ameba as it creeps this way and that in response

to changes in the course of events in the drop of water that comprises its tiny world. Even the apparent spontaneity that it shows upon awakening from a quiet nap, the stretching of pseudopodia and the ameboid equivalent of a yawn, are responses to changes in the interior of its pellucid body—local tensions, hunger for food and oxygen, and the like. From these organic readjustments he pushed the inquiry still further back to the smoothly equilibrated purr of the mechanism of a ship that has found herself and to the cosmic harmony of the celestial spheres.

He goes on to show that human contentment after having safely come out of a trying or annoying experience, like the loss of a hat, and that most animal behavior, and that all mechanical systems in which an equilibrium is restored after an upset of resting conditions—that these are all-of-a-piece. Having recognized that all our conscious acts are natural functions of our bodies, then complacency, or the satisfaction resulting from a successful outcome of a difficult or disagreeable experience, is just another illustration of an organic readjustment to situations as they arise, as a special case of equilibrium restored.

All mentality is probably in a similar way some special kind of striking a balance between clashing or interfering tensions among the nerve centers. Dewey has long taught that consciousness emerges from unconscious action in problem situations. Here are a few quotations from some of his works:

Conflict is the gadfly of thought.

All action is an invasion of the future, of the unknown. Conflict and uncertainty are ultimate traits.

Experience means living. . . . . Experience means primarily not knowledge, but ways of doing and suffering.

A pragmatic intelligence is a creative intelligence, not a routine mechanic.

To maintain the state of doubt and to carry on systematic and protracted inquiry—these are the essentials of thinking.

The most obvious difference between living and non-living things is that the activities of the former are characterized by needs, by efforts which are active demands to satisfy needs, and by satisfactions. In making this statement, the terms need, effort and satisfaction are primarily employed in a biological sense. By need is meant a condition of tensional distribution of energies such that the body is in a condition of uneasy or unstable equilibrium. By demand or effort is meant the fact that this state is manifested in movements which modify environing bodies in ways which react upon the body, so that its characteristic pattern of active equilibrium is restored. By satisfaction is meant this recovery of equilibrium pattern, consequent upon the changes of environment due to interactions with the active demands of the organism.

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CHAPTER XXIV

THE MENTAL ENERGIES

MAKING UP MY MIND

EVERY mechanical process represents an upset of equilibrium which continues until a new equilibrium is established. The same is true of thinking. Thinking begins with an upset of our complacency, an unsatisfied need, a question, a problem, a conflict. When the problem is solved this thinking process stops. I have "made up my mind." The mind is not an active mind, but it is set up ready for action.

The housewife says, "I have made up the bed." Bedstead, mattress, blankets, were there in disorder. It was not a tidy bed, a proper bed-to-be-slept-in. Now it is put in order, a bed-to-be-slept-in; but it is not a bed-sleeping-anybody. The matter rests here until somebody goes to bed in it, when the madeup bed is used to sleep in.[1]

So I may make up my mind to build a new house next spring. There has been long debate and much figuring over costs and resources. Now it is all settled and my mind is composed. I stop thinking about it and turn to something else. It may be six months before I do any further thinking at all about the house. Meantime my mind is at rest, it is not working at all on this question. Not until I begin to do something about it again does the mind made up become an actively real mind; before that it is only a potential

[1] I do not remember where I stole this.

mind. We acquire knowledge and purpose and other mental furniture by thinking, but the mere possession of this furniture is not thinking. That is the active working of the physical machinery of thought.

From this account do not get the idea that what I here call "mental furniture" is packed away in storage and unused all the time that we are not thinking about it or with it.

The furniture in question is more like the equipment of a factory full of complicated machinery. Ordinarily the factory is working full time turning out finished products, say automobiles. Then production may stop for a while and meantime the whole factory is overhauled. It may be a very busy place during this period when no automobiles at all are turned out.

Recently Mr. Ford shut down his factory for a long time. He discontinued the manufacture of Model T cars. For many months nothing was produced for sale. Then suddenly thousands of new-model cars were put on the market. Meanwhile the factory had not been idle, even though no cars were produced. An entirely new car was designed and new machinery was installed to manufacture it. The furnishings of that factory were pretty thoroughly made over so that when production started again the output was very different from what it was before.

So our thinking machinery is not necessarily idle when we are not thinking with it. There may be no output of thoughts at all during this period, and yet the machinery may be very active doing something else which will change the character of the thoughts that we will think when we direct our conscious attention to this matter again. This unconscious cerebra-

tion is what people mean when they talk about unconscious mental operations.

MENTAL TENSION

We have quoted Dewey's remark, "To maintain the state of doubt and to carry on systematic and protracted inquiry—these are the essentials of thinking."

Now doubt means tension, the disturbance of a mental balance or equilibrium. The mental tension may be relieved by bodily activity or by finding an answer to the question and then setting aside the knowledge or opinion thus acquired as a datum for further reference. It becomes a part of our relatively static mental furniture, a "living residue," a memory of a fact, or a settled belief or an opinion. Or the mental tension may be relieved by deliberately refusing to think about it any more. The question has not been answered. I simply try to forget about it because it bothers me.

In this latter case, though I have stopped thinking about the troublesome question and the conscious tension has been relieved, a stable nervous equilibrium has not been restored. The nervous tensions set up by the doubt or question or problem have not been stabilized either by making up my mind to do something or by filing away in the archives of memory some new knowledge acquired or some settled conviction. My *mind* may be quite at rest, for I have deliberately banished the question from consciousness and turned my attention to something else. Yet the nervous tensions are unrelieved at subconscious levels and all sorts of unconscious nervous processes may go on as long as this situation endures.

In perfectly normal life these unconscious processes may rearrange the nervous machinery so as to arrive at some sort of a stable equilibrium, and when my conscious attention is again directed to the question I may find to my surprise that the problem is already solved. I feel that I know "intuitively" what should be done about it. Subsequent experience may show that the solution thus arrived at was right or wrong. But judgments reached by this "intuitive" route are likely to have a very strong emotional coloring; they may for this reason be cherished more ardently than those arrived at by more rational processes. Mystic faith is likely to be reinforced in this way.

Satisfactory adjustments will not come by this "intuitive" route unless the previous experience has included an adequate accumulation of raw data whose recombination in new patterns can give the "insight" which clarifies the problem when attention is again directed to it. The intuitions of slothful minds are not illuminating, while those of alert minds may come out as the inspirations of genius.

When puzzling questions, especially dilemmas of conduct, are put out of mind and tucked out of sight they may not resolve themselves in this way unconsciously or intuitively into satisfactory behavior patterns. Then they keep on popping up into consciousness at inopportune times to disturb one's equanimity. This is especially likely to happen when our natural primitive impulses of sexual gratification, acquisitiveness, *amour propre*, or fear run counter to the established social or moral code of our communities. If the unresolved mental conflict is persistently re-

pressed and banished from mind, the process of conflict may go on at unconscious levels. Then we have what Freud calls a "complex." Such complexes may be built up at any time from infancy to old age.

The normal healthy-minded person is likely sooner or later to see through such a situation and clear it up by deliberately rationalizing it or else he may grow out of it naturally and unwittingly. But many people cannot do this, and the "complex" continues as a violent but wholly unconscious conflict between unrecognized desire or fear and the conduct demanded by the social or moral code. This is pathological and may result in disruption of the personality and insanity, and in all degrees of cutting down the person's happiness and effectiveness.

Freud and his followers have shown how important it is to bring these unrecognized conflicts out into the full light of intelligent analysis and that it is quite practical to check some of these incipient insanities if only they can be taken in time. By psychoanalysis and other forms of mental treatment the concealed conflict, dilemma, or problem is revealed, the unrecognized problem is explicitly stated. Once the nature of the trouble is understood the patient can cure himself provided the disease has not progressed so far as to destroy his capacity for intelligent self-knowledge and self-control. It is the unformulated problem, the unrecognized complex, that plays havoc with our lives.

Unquestionably pathological complexes arise more frequently in connection with sexual conflicts than any others; but it is unfortunate that Freud and most of his disciples have so overemphasized this phase of

the subject as to bring the whole program into disrepute. Moreover, they have developed a technique of psychoanalysis and an elaborate symbolism that smack too much of medieval exorcism to satisfy more conservative physicians and psychologists. Despite these excesses the development of psychoanalysis has pointed the way to a useful method of revealing some hidden features of the personality, both in normal people and in mental disease. For a judicious summary and criticism of this subject the reader is referred to Dr. Gordon's *Personality*.

MENTAL ENERGY

The thinking that I do is the work of a physical mechanism in my body. It can have no effects except as it works with and upon other physical mechanisms. If I am selling merchandise I cannot hope for results except as I talk about it or show samples or do something else with my body that acts on the body of the prospective purchaser.

This mechanistically determined thought process is not passively impressed upon me by outside forces beyond my control. I am an active agent in the matter, for I am the machine that thinks, that is, that manufactures the product. In this I do not differ from any other machine, for all machines make things. And they make them actively, not passively; they are creative agents.

A knitting machine or a dynamo does not make something out of nothing; neither does a brain. Hard thinking is real work. It takes bodily energy and it leaves the body tired. You know that very well if you ever tried it. It is the body that is tired because

it is the body that has been working. A thought is a manufactured product as truly as a pair of shoes or a magnetic field. It has causes and it has consequences. And there is a mechanism that makes it.

So far the thinking machine resembles all other natural machines; but there are significant differences. The cerebral cortex of a human brain is the most complicated single piece of mechanism in our physical universe so far as now known. The products of its action are amazingly diverse and peculiar. Some of them are conscious experiences of what is going on.

The resting body does less work than the active body, the sleeping body than the waking body. The resting nervous system does less work than the excited nervous system. In the chapter on the vital energies there is a description of work done by the nerve fibers that make up the white matter of the brain when they conduct nervous impulses. This is all unconscious work, so far as we know.

By far the larger part of the work of the brain is done in the gray matter. There is good evidence for this. Some experiments suggest that in the brain the gray matter uses about ten times as much energy as the white, but there are no very precise measurements. We also get a rough indication of this by studying the arrangement of the blood vessels. More active regions need more blood. The gray matter is permeated by a much finer meshwork of capillaries than the white matter and those parts of the gray that are most active have more of these minute blood vessels than other regions.

What proportion of the energy of cortical activity is employed in mental work and how much of it goes

for unconscious activities we have at present no means of determining. But that some parts of it go for mental work there can be no doubt.

In the cortex are the most important centers of control of our behavior. Much of this work is done unconsciously, "automatically," as we say; and even this unconscious effort is a more expensive kind of work than is needed for the simpler reflexes. But part of the cortical activity is conscious, and this is the most expensive kind of work that we do.

MENTAL EXHAUSTION

Two kinds of conscious activity involve very different amounts of work. Some of our experiences come "of themselves"; they may be forced upon us by what is going on around. Observation of the common happenings of the street or office is not a very strenuous exercise. This sort of "involuntary attention" does not ordinarily tire us very much. But too much of it may. The most heedless and unthinking tourist may find himself at the close of a day of sight-seeing utterly exhausted, even though he has not been exercising very much and every step of the way was directed by a guide who spared him any consciously directed mental effort whatever.

The other kind of consciousness is voluntarily directed. That is real work, and the most exhausting kind of work that we do. Everybody who has ever done any long-sustained hard thinking knows how after a while his head gets hot and his feet cold. The brain is working very hard and drawing vital energies away from other parts of the body. To try to do hard mental work immediately after eating a hearty meal

is stupid and dangerous. Each of these enterprises makes severe demands on our total resources of bodily energy, and to persist in trying to do both of them at once is bad for both and in the end may wreck the bodily machine, which is not constructed to stand this kind of a strain.

Hard mental work not only fatigues the brain quickly, but if carried to excess for long periods it uses up the reserves of tissue and results in severe and enduring depletion of vitality more than does hard muscular work.

What is commonly called "nervous exhaustion" is a general depletion of nervous reserves, probably chiefly in the gray matter. This kind of exhaustion can be recovered from only very slowly, as everybody knows who has had to take a "rest cure" and as many other people should understand but don't—people who need long-continued rest but are not willing to take it.

There are some experiments that go to show that steady mental work is less fatiguing than steady muscular work, or at any rate that one can keep at it longer; and we all know that in emergencies the mental spur can drive jaded muscles on long after they would give way in utter fatigue without the frenzy of fear or anger or the compulsion of an indomitable will.

But here we are not talking about these "acute experiments," as the physiologist calls them, but about the general exhaustion resulting from long periods of steady work. Common experience is that when an athlete "goes stale" from overtraining his muscles he may get back into fit condition far more

quickly than one will be able to do if he "goes to pieces" nervously from mental overwork or worry. The nervous wreck is a very sick man; he is sick all over, not in some detached psyche. Recovery from this sort of nervous exhaustion is a very slow process and it doesn't pay to get that way by overwork or worry. This is why school children should be given, not only the short holidays of the week-ends, but also the long vacations. Even their teachers—most of them—need the same opportunities for complete change and relaxation.

CONCLUSION

From this survey of the origin and significance of mind in nature it appears that historically in cosmic evolution and in personal development unconscious mechanisms precede conscious mechanisms. Consciousness arises within behavior. Having arrived, it makes the behavior more effective.

The conscious animal can do kinds of things that the unconscious animal cannot. It can also have satisfactions and dissatisfactions with what it does. The dissatisfactions, the unsatisfied needs and desires, are powerful motives for more strenuous endeavor, for expanding experience, for richer and more productive life. Consciousness, we repeat, is not an expensive but useless luxury. Biologically considered, it has use or adaptive value as truly as have the colors and perfumes of flowers, the songs of thrushes, the maternal instincts of hens, and the complex of endocrines in our own bodies.

Good mental work is the most valuable thing on the market, and the most costly. The biggest prob-

lems of industry, commerce, and government are not concerned with the supply of material commodities, but with the supply of men; not brawn—that is cheap—but brains. The big pay-checks go for the work of brains. Good constructive thinking always commands a high price for the same reason that diamonds do; it is resplendent and it is rare. Fine sensibilities are more to be desired than rubies; they are priceless.

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PART IV

HUMAN NATURE

CHAPTER XXV

IS MAN A MACHINE?

REGULATION

THE pioneers of mechanistic biology in this country did valiant service in clearing the ground of popular mystical notions which blocked the way to further scientific advance. But some of them seemed to have a very primitive idea of mechanism and to overlook the radical differences between living machines and all others.

Some of the present leaders of research in the fundamental mechanics of heredity and general physiology also seem to fail to carry their scientific thinking through to the end of the program. So able a physiologist as J. S. Haldane says: "Co-ordinated or regulated activity is a primary feature in life. In other words, the functional significance of biologic structure and activity is of its very essence. The application of the word 'mechanism' to life amounts to the assertion that this is not true."

As already repeatedly pointed out, it amounts to nothing of the sort. It amounts, rather, to the recognition of the obvious fact that a living mechanism is a different kind of a machine from a power loom. But not altogether different when it comes to co-ordination and regulated activity. Even the loom works as a whole and the "functional significance" of its several parts is missed entirely unless we look at it as a whole

and see how part co-operates with part in the production of a woven fabric of some complex pattern. It even regulates its own activity, for if a thread breaks anywhere in the whirr of the machinery the loom is automatically stopped until the attendant repairs the damage.

The live animal's co-ordination and regulation are of a different kind and are far more complex; but they are just as truly mechanistic. If our notion of mechanism is too narrow to embrace all that the dead mechanism does, to say nothing of the live one, then the trouble lies in the poverty of our notions, not that of the machines.

ADAPTATION, INVENTION, CREATION

Mr. Will Durant has recently written an incisive article entitled "Is Man a Machine and Life the Passive Product of External Force?" and of course he answers his double question in the negative, as he should. But there are two questions here, and the answers may be different depending on our definitions. His argument is so typical of current criticisms of the mechanistic position and so clearly stated that we can well afford to summarize it.

After a sparkling review of the history of the mechanistic idea, he gives a list of vital processes which illustrate the differences between dead machines and live animals, followed by a triumphant demonstration that living things are not machines of the same sort as others and man is not like the machine that he invents and feeds. "Is human behavior of the same order as the erosion of the hills?"

Of course not. Nor is the erosion of the hills "the

passive product of external force." It is the active work of that mechanism which we call a river system.

Onc of the fundamental laws of mechanics, whether we deal with natural mechanisms or artificial ones, is that action and reaction are equal, and the business of the machine is to react. The reaction is equal to the action applied in amount of energy but not in pattern of performance, and one of the chief uses of machines is to effect these changes in the patterns of energy. That is what they are for, and yet we have been so impressed by the exact balance of the energy equations that we have neglected the changes in the way this energy behaves, the very thing which gives the machine its significance.

Machines act as well as react. They all do. The kind of action depends on the kind of mechanism. The energy all comes from the outside, but the product depends on what is inside. Now that we recognize this elementary fact, we must re-examine the question, "Is man a machine?" What is inside of a man is radically different from what is inside of the machine that he invents and feeds, so the product of its action is of course different. The argument so far certainly does not prove that the man is not a machine.

Next follows a restatement of current mechanistic views which is so well put that we quote it. The mechanists claim, "not so much the machine-like character of human behavior, as the inviolable sequence of cause and effect in the mental as well as in the physical world. Man is a part of Nature, and is presumably subject to her laws." This I accept as a fair statement as far as it goes.

I also accept and cordially support his spirited attack upon those naïvely fatalistic philosophies that are now so popular among mechanists, but I would work it out differently. He says that you are not "the helpless recipient and victim of whatever stimuli may chance to impinge upon your flesh. You are an agent of selection." Quite so. And so is a set of self-registering meteorological instruments; so is a river which selects the fine silt and leaves the heavier gravels at different places depending on rate of flow; so is an ameba when it selects a live animalcule as food and rejects a similar bit of mud. But the mechanisms are different; the things selected are different; and what is done with them is different. One may be as mechanistic as the other. We must not decide this question until we find out.

Again, adaptation of the environment to my needs is played up as a distinctively human characteristic. But every organism does this and every natural mechanism does it. The river does it. We do it better. We are not rivers or beavers. This adaptation, so far from being non-mechanistic, is the most significant thing about the machine. It is interaction between a mechanistic system and the environment within which it works. It is an illustration of the rule of coming back to a balanced state after an upset of equilibrium which has already been mentioned as characteristic of every mechanism, natural or artificial.

Mr. Durant says further, "In this process of active adaptation we perform mental prodigies which only a fanatic would conceive as mechanical." Yes, if we define mechanism as a passive thing, acted upon but not acting. But if we enlarge and rectify our ideas of

mechanism—all mechanism—to include an active participation in shaping the course of events, not by adding energy but by redirecting it, then the present writer freely admits that he is just that kind of a fanatic. I claim further that objection to a radically mechanistic view of all nature, including human nature, can be based only on ignorance of what mechanism is—all mechanism, and especially the mechanism of the cerebral cortex that does our thinking and performs the other mental prodigies.

So far we have found no ground in this argument for denying that man is a machine. But how about our marvelous capacity for creating things, for invention, for imagination? Mr. Durant puts it more modestly. "We are in our little ways creative centers in the flux of force." True, but mankind has no monopoly of creation. Every machine makes something. That is why we are willing to spend money for it. We have already commented on the fact that the river creates a delta, bees create honeycomb, beavers create dams and cunningly devised houses. Human invention is different from these, for we can create airplanes and epic poems; we can even take part in the creation of a moral code and a personal character. These are truly unique, but so are the beaver's houses unique, and none of these things is separated from the others by unnatural or supernatural barriers. They are all part of that nature of which each one of us is also part.

"Life is creative, not because it makes new force from nothing, but because it adds its own remoulding force to the powers that enter from without." This seems to be exactly our position, though but for the

context one might criticize the expression "it adds its own remoulding force." The passage might be recast in this form without any change in the author's meaning, if I understand him correctly: "The living body is creative, not because it makes new force from nothing, but because it performs work in changing the form of the energy which enters it from without." This is just what every other machine does. The pattern of the performance differs according to the structure of the mechanism that is working.

When Mr. Durant says, "The mechanical approach is breaking down in biology, in psychology, in physiology and even in physics itself," this applies only to a popular brand of mechanistic philosophy which is not true to the facts, even the facts of inorganic machines. Our ideas of mechanism and determinism are being revamped to accord better with the facts. We are recognizing the law-abiding character of all natural processes and that every mechanism does creative work. Some of them even create themselves, as in species formation in the evolutionary series and character building by human beings.

The prevalent idea that everything that is or ever shall be in our cosmos was predetermined and foreordained at some unknown beginning has no scientific support and is contrary to the evidence. New things do happen, new things are made, and this is done by natural agencies. This is the way nature works.

DETERMINISM AND MECHANISM

An exceptionally gifted and competent zoölogist, H. S. Jennings, has paid his compliments to current conceptions of mechanism in this wise. I condense his own statement.

Mechanical science asserts that all action is determined by the conditions preceding it. There is then no chance of *our* altering what was predictable before we came into existence. Mechanical science thus leads to fatalism. All action is determined by the physical conditions—materialism with all its gross consequences. Ideas and all that is mental are left without function in the scheme of things. They ought not to exist. And if they do, they might as well not. The objective examination of behavior leaves no rôle for the psychic.

Mingle this perfect doctrine of mechanism, as has been done, with equal parts of the perfect doctrine of natural selection, and you get a potion, a cocktail, with a kick that is warranted to knock out ethics and civilization.

Now Jennings has no more use for this kind of mechanistic biology than have I or had William Jennings Bryan. It does not fit the facts as we know them. He meets the situation in human affairs by accepting determinism—that is, "what happens depends on the conditions"—but throwing out of biology mechanism—that is, "the explicability of all that occurs in the living through a knowledge of the laws of the non-living." He says further:

"Only on the basis of determinism is science possible; only on the basis of determinism is learning by experience possible." There is a general impression that mechanism as above defined has a monopoly of determinism. "But this impression has no justification."

Neither Jennings nor I are mechanists of the brand here painted. He gives up the mechanistic principle in biology; I clarify it and so do not have to give it up. If we correct our inadequate ideas of what mechanism really is, our biology and our psychology become as mechanistic as our mechanics.

As to prediction, we can foretell what a known mechanism will do under given conditions provided we have had experience with this combination of things before. But we have no basis at all for prediction of what a wholly unknown mechanism would do or a known mechanism under conditions of which we have not had any experience. The only way to know is to find out by trying it. Only Omniscience could know without trying it out. And mechanists have faults enough already without adding to them by claiming to be God and knowing everything.

When an entirely new configuration of things arises naturally, or first comes to our knowledge by observation, we cannot predict what it will do next until we learn the laws of its behavior by further observation and experiment. Then we may have to formulate some new laws of nature to fit the new facts, as we did when radium was discovered. The old laws have not been rescinded, but they do not apply in the new field. As Jennings says, "The statement that the laws of nature are immutable must not be construed to mean that new laws shall not be exemplified as new conditions arise." And again, "The desires and aspirations of humanity are determiners in the operation of the universe on the same footing with physical determiners."

The simpler mechanistic philosophies and metaphysical vitalism both represent movements of thought along lines of least resistance, which alternative being chosen apparently depending on the philosophical attitude or temperament of the student. They grow out of an intellectual demand for a simple way out of an unresolved situation. The safer scientific position at

present is an open-minded agnosticism regarding the ultimate philosophy of nature, accepting mechanistic explanations as far as they can take us and keeping in mind the distinction between the energy as quantitatively manifested and the pattern of that manifestation. These, as previously mentioned, are never dissociated in reality and patterns, when our knowledge is completed, may also be expressed quantitatively. In the meantime many of them must be accepted and used with such scientific precision of analysis as may be possible.

DETERMINISM AND MATERIALISM

It is of the utmost importance that we do not for a moment lose sight of the fact that the most radically mechanistic view of nature and of human life does not require the acceptance of a materialistic philosophy. The very general confusion of deterministic and mechanistic science with materialism as a philosophy of the ultimate or essential nature of things must be cleared up before further progress can be expected. The facts of our common and scientific experience can best be formulated in deterministic and mechanistic terms. These same facts do not point so clearly toward any one of the current philosophical systems which deal with the absolutes or ultimates that lie beyond our experience. I may add that in my opinion, so far as they shed any light on metaphysical questions, they point definitely away from materialism as usually formulated.

With better understanding of the mechanisms of erosion, of species formation, of thinking, of desiring, and of aspiration, we see that all of these things are

determiners in a unitary mechanistic cosmos. We have a conception of emergent evolution that has nothing mystical about it. We need no categories which are not related in cause-and-effect series with inorganic mechanisms to embrace all there is in life and in human nature. The unity of the natural order remains unbroken. But we do need to recognize that the vital patterns of combination of simpler inorganic processes are different and that the conscious patterns are different from the unconscious.

The conclusion is that the widespread hostility to the mechanistic conception of nature and of life is based on an inadequate view of what mechanism is. The fault lies not in the inadequacy of the mechanisms to do the work of nature and of mankind, but in too narrow a conception of mechanism in general.

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CHAPTER XXVI

CONTROL OF BEHAVIOR

INORGANIC AND ORGANIC CONTROL

CONTROL of events is the main business of all mechanisms. This control is exercised in part upon what is going on outside—control of environment—and in part upon the internal processes within the mechanism itself—self-control. This applies throughout the mechanistic realm, and the foregoing chapters are full of illustrations of it.

The living body has greater capacity for self-regulation than any other kind of mechanism on earth. On a still bigger scale the astronomers give us equally impressive instances in their accounts of celestial mechanics.

The living body grows, it repairs its own wear, and it reproduces its kind. If mutilated, not too severely, it can repair the damage. A salamander or a crab can grow a new leg if one is cut off. Men cannot do that, but they can grow new nerves to supply sensibility and movement to an arm that has been paralyzed by cutting a nerve trunk, though this sometimes requires the help of a good surgeon.

The living body also in the course of time can change its own inherited pattern of internal organization in adjustment to changes going on in its surroundings. It makes itself over to suit new conditions. This is creative evolution.

These are the familiar properties common to all living bodies which set them off over against all non-living mechanisms. They employ mechanistic principles in ways determined by their own organization, the same as other machines do—in their own ways in each individual case. The efficiency of the vital processes may be measured in terms of the pattern of this control over the flux of energy and material which is exercised by the living body.

MECHANICAL CONTROLLERS

The apparatus of control is familiar to us in all inorganic machines. The "controller" of a street car enables the motorman to make the car do what he wants it to all the time. This is because the workings of the internal mechanisms of the car are controlled by the levers under the motorman's hand. The controls of an airplane or an automobile work the same way. This control which is exercised from the outside works out properly because the internal mechanisms of control are appropriately designed and constructed.

Many people think the human body is controlled this way from the outside. This is not necessarily true, for much machine control is wholly automatic. It works without a motorman or a pilot; it is wholly internal. A big gyroscope may stabilize a battleship wholly by internal control. A typecasting machine when once started goes on about its very complicated business of turning out *a*'s or *b*'s all day long without any supervision by the operator.

A well-known mechanical toy described by Lotka is made in the form of a beetle which when wound up will move in a straight line across the table. It

"walks" on two toothed wheels, one of which is an idler while the other is rotated by the spring (Fig. 8). In front of these there is a third toothed wheel smaller than the others and placed at right angles to them, transversely to the direction of forward movement. This wheel is running idly until the toy approaches the edge of the table.

The beetle has a pair of feelers projecting forward. One of these has a curved tip which slides along the

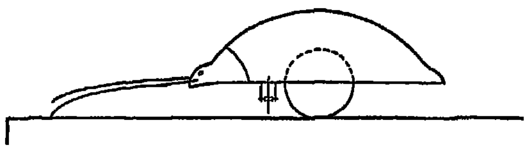

FIG. 8.—Diagram of toy beetle. (From Lotka's *Physical Biology*, by courtesy of Williams & Wilkins Co., 1925.)

table top. Having reached the edge of the table, this tip drops down and allows the front end of the toy to drop a little because this end was formerly held up by contact of the feeler with the table. When the head of the beetle is lowered in this way the small transverse wheel comes in contact with the table. This makes the toy turn and changes the direction of movement until it runs parallel with the table edge. It is kept in this direction by the curved feeler whose tip is dropped over the edge and so prevents the beetle from turning farther away from the edge.

This little automaton has a sense organ or "feeler" which warns the mechanism of the approach to the edge of the table. Then the internal control apparatus operates reflexly to change the direction of locomotion so that the machine is not wrecked by falling off the edge. The design is clever and very simple.

REFLEX CONTROL

This toy automatically controls its own behavior so as to avoid self-destruction by falling over a precipice. Many of the tropisms (turnings) of lower animals and many of the reflexes of our own bodies are equally automatic. Their machinery is much more complicated but in some of these cases it is understood nearly as completely as we know the apparatus that controls the movements of the toy beetle.

One of our most complete accounts of these is Sherrington's study of the scratch reflex of the dog. A flea-bite anywhere in the "receptive field" that can be reached by the dog's hind leg calls forth a scratching of the exact spot bitten in a very precise way. The details of what happens and of the mechanism that is working are very minutely and accurately described. The nerve centers involved are in the spinal cord. The brain has nothing to do with it.

This reflex in its simplest unconditioned form is wholly unconscious. Of course, consciousness of what is going on may be added, and in this case the brain is linked up with the spinal cord and an additional cerebral mechanism is now called into play. I may, for instance, teach the dog not to scratch in the house. The unconditioned reflex is checked by training, that is, it is conditioned by memory of previous experience of punishment or scolding, so that now the dog either endures the irritation stoically or else goes out of doors to scratch.

The mechanisms employed in these tropisms and unconditioned reflexes differ from those of our toy beetle not only in being much more complex, but also in the way in which they were made. The toy was

designed by an ingenious mechanic and was manufactured as a commercial enterprise. The idea is so clever that one hopes the inventor made a lot of money out of it.

The live beetle grew into its present form naturally. It can control its behavior so as to take care of itself in more different ways than the toy, and it was designed by a natural process that we call "organic evolution." It made itself and it runs itself. This ground we have already covered. Biological control of behavior is self-control from start to finish.

Of course this power of self-control is not unlimited either in the case of the toy beetle or of the live one. The toy beetle's control is limited to making only one kind of a turning in one particular situation, that is, at the edge of the table. The live beetle can make many kinds of turnings or tropisms. These have been accurately described and shown to follow their stimuli mechanistically. The mechanism is correspondingly more complicated. But the live beetles cannot control their behavior well enough to avoid destruction in countless numbers by the ordinary hazards of their precarious existence.

HUMAN CONTROL OF EVENTS

All of the different kinds of tropism that the live beetle shows can be imitated by mechanical or scientific toys, and have been—turning toward or away from the light (phototropism), turning toward or away from particular chemical substances (chemotropism), and all the rest. But nobody has ever assembled all of these in one machine as they are in life.

On the other hand, the behavior which expresses

itself as biological reproduction has not been duplicated by any man-made machine. We have not learned how to do it, and present indications are that we are not likely to for a long time to come. Live beetles and all other living things can do it and have been doing it for hundreds of millions of years. We have not yet learned how to control vital processes so completely as to be able to make a live animal out of dead stuff the way God is said to have done in the Garden of Eden, though the newspapers insist on ascribing such marvelous powers to eminent biologists every now and then.

Yet we can control the course of events in living bodies in ways that are very useful to us. And the more we learn about vital processes and their mechanisms the greater is our ability to control the course of life in our animal neighbors and in ourselves. "As the twig is bent the tree is inclined." We can bend the twig. We do this with children too. That is why we send them to school.

We can control the course of heredity in any animal or plant stock in a large variety of ways. This is how faster race horses, better milch cows, fatter pigs, and hardier grains have actually been created by agriculturists. This means that we can control the course of evolution, for many of these artificially produced strains breed true and when they are thoroughly bred into a stock we have a new species. This is the way new species are made in nature, and natural species endure as long as the conditions that called them forth endure. Artificially created species may also persist as long as the conditions devised for their production are maintained.

MENTAL CONTROL

The ancients taught that the control of human destiny rests in the lap of the gods. We believe now (most of us) that part of it rests with us. It is ours if we will reach out and take it. Some control of the courses of our lives is our natural birthright. This we share with all animal kind, but we do it differently from other animals.

In human control, whether of our environment or of our own behavior, we must recognize that mental acts with the related bodily changes are the most significant features of the causal complex that is operating. Man controls his environment by the same biological methods that ants and beavers do, and he carries the process much farther by new methods of intelligent observation and experiment. He also has himself under better control, again partly by reflex and other unconscious mechanisms and partly by intelligent attention to it.

The mechanisms of conscious control are so different from those of all kinds of unconscious control that very different results are secured. When the mechanisms of consciousness reach the grade of organization that permits the formation of general ideas and of ideals of future conduct, these ideals of what I want to do, to be, and to become are causative factors in determining what I do now.

I now shape my present conduct in view of possible future events and in view of the effect which my present act may have on the future. I see several ways of reacting to the request of a friend for the loan of five dollars and my decision whether to accommodate him or not is based on my look into the future. Will I

have enough left to see me through to pay day? Will he be able to pay me back? Will he actually want to pay the debt when he gets his own pay check or will he be more likely to spend it for a week-end at the country club?

This conscious forecast of the future effect of a present action is certainly a causative factor in determining whether I lend the money or keep it. It is a function of my brain, and the decision arrived at is the result of countless causal factors in the situation, some of which are unconscious and some deliberate intelligent judgments. It is mechanistically determined and yet it is a real choice. The fact that I know why I choose one or the other ways of deciding the question, this knowledge and this prevision of consequences, are by no means negligible by-products of the situation. They are the key-factors, and they set this kind of a choice over against that of a locomotive which when the switch is turned leaves the main track to enter a siding and does not know anything about it.

This intelligent choice is not an uncaused action, and yet the choice or decision that I make is far removed indeed from all forms of unconscious adaptive behavior. A weather vane turns with the wind. It has no choice in the matter. A moth flies into the candle flame and sears its wings. It apparently has no choice about it; its phototropisms work this way automatically. Under natural conditions these tropisms work out beneficially more often than injuriously. If it were not so the tropism would not be there, for the individuals having the destructive tropisms would all be killed off without propagating

their kind. Candle flames are not the sort of hazards to which a moth has to adjust in the natural environment within which the tropism was established.

We have only to recognize that thinking in general and especially thinking ahead and planning for the future are natural functions of my body to see that this foresight is one of the causes which determines my present behavior when I am asked for a loan of five dollars. There is nothing unnatural about my ability to do this. It would be unnatural for a moth to do it because the insect has not my kind of a brain. He has not the mechanism for foresight and for my kind of a choice.

In every case where there is conscious foresight of the probable results of an action this mental act becomes a causal factor in the present behavior and the total situation is radically changed. It is now a choice as we ordinarily use the word. This act is purposive or intentional, while that of the weather vane or moth is not. And yet it is not uncaused.

Right here is where many people are likely to jump the track in following this line of thought. They have always considered purpose, choice, self-control, and character-building as implying some mystical and unnatural powers that cannot be fitted into a mechanistic scheme, and they are unable to use these words at all without loading them with some supernatural implication.

But it is a fact that we do make decisions and choices and that we make them in view of the probable effects of the choice upon future events. There is nothing supernatural about this. Now having shown that every choice is a natural function of a natural

body and that it has causes and results, that it is part of the mechanistic system, we have not changed in the least the enormous difference between the unconscious tropism or reflex and the conscious choice made deliberately with foresight of its probable consequences. Nor have we altered the fact that these conscious choices give us humans an apparatus of control of conduct that none of the beasts possess. The beasts do not make our kind of choices and so they cannot show our kind of control of present and future conduct.

It seems to be quite impossible to get some people to see this simple fact. We are so accustomed to think of choice or purpose as due to the intervention of some external and unnatural mystic power, a "spirit" or ghost, that we cannot use these words at all without immediately invoking magic, some undefined power that breaks into the natural causal sequence and disrupts it.

Now, of course, the author might meet this inveterate tendency of people to clothe his words with mystical meanings, which he has expressly and most emphatically disclaimed and excluded, by avoiding altogether the words "choice," "self-control," and the like and using some more vague circumlocution. But why do this? Why say "electron-proton interaction" when you mean choice? Choice is a perfectly definite thing. We all know what the word means because we all make choices every day of our lives.

Though these common human choices and purposes are not uncaused, they are nevertheless really different from the discriminative reactions of toy beetles, moths, and human reflexes. There is a mech-

ansim working in each case. The mechanisms are different and the control of behavior effected is correspondingly different. Our choices are real choices, and they are *our* choices, choices made by our bodies, not by some mystic power that controls us from the outside the way the motor car is controlled by the driver.

PURPOSIVE SELF-CONTROL

Prevision of future contingencies, then, does actually participate in the control of human conduct in a natural way. It is a determining factor in what I do now. Indeed, it may go further than this. I may foresee the effect of the choice, not only on the course of outside events and the actions of other people, but also on my own character, my own inner nature. I may need that five dollars myself and I may have serious doubts whether my impecunious friend will ever be able to pay it back. Nevertheless I may lend the five to him with a smiling face and mentally kiss it goodbye. Not perhaps because he is really in hard luck and I am sorry for him, but because of its effect on myself. I have noticed a tendency to become close-fisted and selfish. It will be good for me to loosen up a bit and give my generous impulses a little exercise.

Here is conscious, deliberate effort directed toward a change, not in my environment, not in the interest of my bank account, but in my personality, my character. Without thinking it out very critically perhaps, I am nevertheless really changing myself—for the better, I hope. And I am doing it with my eyes open. I have already some ideals of what kind of a man I want to be. I have decided that I do not want to be a tight-wad. Occasionally yielding to a generous im-

pulse gives me more pleasure than a fat bank account. I recognize this and I deliberately cultivate generosity.

The laws of cause and effect have not been violated, but they are certainly working in a very different way from that which we see in the locomotive when it takes the siding or in the unconscious conditioning of reflexes in a worm or a rat. Both the unconscious and the purposeful exercises are creative. Both create habits, in the one case blindly, in the other intentionally. What is the difference? The difference between a cog in a tiny wheel of the toy beetle and the intelligent designer and maker of that clever mechanism.

Our toy beetle exhibits real internal control of behavior. The live beetle more of the same and better control. I myself control my own behavior mechanistically just as truly as the toy. The range of that control is greater. I can reach out more widely into my environment and make it useful to me in more ways than the toy or the live insect can do. I can even reach out in imagination into the future and use possible contingencies as causal factors in shaping present conduct. And in the course of this adjustment to environment I can change my own inner nature and control the course of my own future growth in knowledge and character as the toy cannot do at all and as the insect can do very little. Yet the control is as natural and as lawfully systematic a process in my own case as in the others. The laws are different and so the results are different.

Since mental acts are natural functions of our natural bodies, they are real determiners of conduct

and character the same as are all the rest of our acts. They are part of the biological machinery of regulation and control as truly as are our reflexes. Self-control by voluntary effort is a bodily act; hence it can be strengthened and cultivated by training as truly as muscular control in riding a motor-cycle can be trained, and for the same reason. It is the body that is trained in both cases.

This control is worth something to us. It is worth cultivating and it can be cultivated. Do not let anyone swindle you out of it by claiming that it is a myth or by trying to foist upon you some makeshift substitute warranted to be just as good and easier to live up to. It isn't. Nothing can replace it without sacrifice of your birthright as a human being. It is the most real and valuable bodily function that you have. It is worth holding on to and working for with all your might. There is nothing magical about it. It is bodily work, and hard work. It tires you out more completely than anything else you can do.

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CHAPTER XXVII

VOLUNTARY CONTROL

WILL-POWER

OF LATE we have had numerous books written to assist us in the cultivation of will-power and self-mastery, some by highly gifted authors. Doubtless they have been useful in counteracting the fatalism of a crudely mechanistic age; but somehow many of them lack punch for some of us who are not ashamed to call ourselves mechanists, not because they stress the spiritual forces that control our conduct, but because they seem to leave these forces suspended in a vacuum with no practical contacts with the physical organism through which alone they can make good in conduct.

When, for instance, Mr. Arnold Bennett says, "The brain is a servant exterior to the central force of the ego," one wonders about this mysterious ego. We know where the brain is, but where is the ego, whence does it derive its forces, and how do these forces impinge upon our mortal bodies which alone can do anything about it? What is the mystical "life-force" to which these authors appeal and how does it work to move our muscles?

Will-power may be the force that moves the world, as some of these writers maintain, and the brain may be the lever that transmits this force to inactive and perhaps reluctant muscles, but how does an extrane-

ous spiritual ego act upon matter and where is the firm fulcrum of our lever? Until these questions are answered or shown to be irrelevant these eloquent pleas are likely to leave us very much in the dark about how practically to go at it to cultivate this mystic will-power and how a will, be it never so cultivated, can actually make us behave either better or worse than we would without it. Sonorous echoes in cathedral-like emptiness (to borrow one of H. G. Wells's expressions) may be very entertaining, but their motive power is small.

Mr. Bennett is saying words that no biologist can understand, not because he (the biologist) does not recognize a unified control of the personality and not perhaps because he is unwilling to admit spiritual components in this control, but because brains, like viscera, are physical organs and he knows of no way by which material processes like nervous conduction and muscular contraction can be set in motion by non-physical or metaphysical agencies like the ego of the schoolmen. There may be another explanation for all of the facts, an explanation that does not take us beyond the realm of scientifically verifiable experience. Let us look a little further before slipping into mysticism, which from time immemorial has been a favorite device for wriggling out of tight places.

Whether my three-pound brain is the servant of the ego I do not know, ~~but I am sure that~~ it is master of the seventy-five pounds of muscles that run my errands.

Now don't jump to the conclusion that I do not believe in the reality of will-power and in the possibility of its cultivation. I agree with Mr. Bennett

that this is the most important thing in education, but I do not like his way of going at it.

To resolve that I will strengthen my will and then expect this good resolution to do the work by some transcendental miracle is about as effective as my early practice when trying to learn to play golf. I was nervous and tense. The instructor impatiently told me to relax, so I put my will-power to it, braced myself for the effort, and growled through my clenched teeth, "Now I will relax."

We have no will-power without the organs of will-power, and if these are undeveloped we cannot grow them in a minute. The half-grown child cannot by taking thought add a foot to his stature; but the foot will be added naturally if he takes proper food and exercise and keeps his growing machinery in order. He can also add to his will-power by the same indirect means of cultivation, and fortunately he does not lose the ability to do this when he grows up.

But we have to learn how to do it, and so far we have not been very successful in this. We do acquire by muddling along some measure of self-control and most of us do manage to improve our will-power somehow.

"If the iron be blunt, and he do not whet the edge, then must he put to more strength." But brute strength with a dull tool cannot always give a finely finished product. If we look to our tools we shall not only save labor but get a better product. Let us see how this works out from the naturalist's standpoint. If we can visualize the mechanism of self-control we may be able to work it better.

WILL-POWER IS SELF-CONTROL

Will-power is an expression of self-control. To drift along buffeted hither and yon by every wind of circumstance without active effort on your own part to direct your course, or to yield pliantly to every blind impulse and every drive of emotional passion, these—both of them—are signs of a flabby will. A strong will is something positive and dynamic. It involves the expenditure of vital energy; it is the performance of work. This means that some bodily organs are working when I make up my mind to improve my game of golf and then force it through to a successful consummation.

The successful act of will is a very complicated performance. It is no simple fiat of a metaphysical ego floating free in empty space nor a transcendental aureole or penumbra playing around my mortal frame. It is the mortal body in action. It is first a craving or impulse for something. This may arise as an emotional pulse originating in the visceral and reflex apparatus quite below the level of conscious purpose. But when it becomes a purpose there is an intelligent appraisal of it. The cerebral cortex comes into play and rationally analyzes the impulse, evaluates it, weighs the advantages and disadvantages of the end in view, considers the means to be employed and whether the end desired is worth the effort it will cost, comes to a decision, and finally puts the decision into action. The will to do which rests at the stage of purpose is still-born.

I am a wretched golf player. I generally delay the game by knocking around in the rough and losing my

balls. It takes the joy out of it. But I like the sport and the society of my cronies in the open air. To get this satisfaction I must be able to keep on the course and not waste my time and theirs looking for lost balls. All right; this means I must improve my stroke. The motive is there and the purpose is formed. I go to an instructor and take some lessons.

The growth of this purpose is readily seen. It is a perfectly natural growth. The organs at work we know something about. They have already been discussed. Those which work unconsciously and those which work consciously are knit together into a single fabric, a flowing network from which arise wish, impulse, trial, failure, spiced with an occasional brilliant success, and all held in place by a deliberate intention to achieve the satisfaction desired. Now, of course, I do not reason this all out in syllogistic form; but as I look back over the history of the season's play this is about the way it works out.

So much for the purpose, the decision that I intend to improve my game. But how about volition? Is the exercise of will-power finished when I make the decision to employ an instructor? No, it is just begun.

During my first lesson I played a worse game than ever before in my life. I went all to pieces and every drive was a foozle. The next was but little better. Discouragement. Attention upon stance and all the technical details of a proper form disrupted the subconscious automatisms and everything went wrong.

Now was the real test of will-power. Evidently I must make these automatisms all over from the ground up. Bad habits must be broken and new ones

made. You can't do this by sitting down on a bench and wanting to. These new habits can grow no faster than the nervous and muscular organs can be changed and linked in new patterns. The older you are the longer this will take.

The test of will-power is my ability to stay with the job. This must be backed by a judgment whether the game is worth the candle; whether golf is worth to me what it will cost in time, money, and hard work. I decide that it is.

Very good. The purpose is revived and strengthened. Now will-power comes into play again and I keep doggedly at my daily practice. It is voluntary effort that carries me through, an effort sustained and renewed day by day, reinforced by every fervid emotion that I can command and steadied by intelligent attention to the successive steps to be taken.

Finally I arrive at a passable result. Having no ambition to win prizes, I am content with a score that measures up to the average of the foursome and that enables me to hold my place without the humiliation of gumming up the game every time I go on the course. Having reached the desired stage of proficiency, the intense voluntary effort ceases and I enjoy the game with just enough of ambition to excel to give zest. The sheer pleasure of the sport now carries me on; active exercise of will-power is no longer necessary; that phase is passed.

This story of the way will-power really works in a concrete situation tells us what we want to know about the relation between will and self-control. Volition is self-control.

CULTIVATION OF WILL-POWER

The mechanisms of control we have discussed already. All machines control the energy and materials that pass through them. That is what a machine is. The living machine controls the vital energies according to vital patterns and biological laws. The social machine controls the energies of human life as these work out in communities in accordance with laws of sociology. These are all orderly processes; when we know causes we can predict results, and sometimes we can control them.

The development of the individual personality is also an orderly or lawful process; it is a growth. We have only to understand the laws of this growth to have it under some measure of control. Like all other growth, it is an interplay between the organism and its environment. So a part of the machinery of control of the growth of the self is outside of us, and the environment, even the social environment, can be changed to suit our needs and desires. This ground has already been covered.

But after all, the most significant part of the apparatus of self-culture and character-building is inside of us, and control of the growth of these bodily and spiritual powers is our immediate interest now. The laws of this growth are partly those of general biology, partly those of psychology, and partly those of sociology. These are inextricably interwoven, as was apparent in our survey of the development of skill in playing golf.

It is the conscious elements of this complex that count for most in self-culture because these give us the

motives and purposes that set the direction of our exercises and so determine which of our latent powers or potentialities of further growth will actually be matured and strengthened. Voluntary control keeps us at it. Emotion activates the machinery of behavior and intelligence directs and regulates it.

This is our will-power—power to carry through to the finish some enterprise that we want and to direct all of the vital energies into that channel, to canalize our bodies so that our efforts come out in some desired way. Continued exercise of this power deepens the channels and ultimately creates the vital machinery for doing this sort of thing with almost automatic precision. Then will passes over into habit and we say the character has been matured or formed—for this particular kind of work. The control which originally required the utmost expenditure of vital energy and absorbed our conscious attention now goes on of itself, it is our second nature, because the apparatus of this particular kind of control is built into the organic fabric of our bodies. We have acquired something tangible, a better body with better control of its activities and of its adjustments to the world of affairs and people. The body can control its own reactions to these things by as natural a process as the turning of a sunflower toward the light is controlled by the mechanism of its phototropism but with a bigger apparatus and a better result.

The development of will-power, then, is a creative process. We can generate this priceless power only when we have the proper machinery for it. The particular act of volition is the working of this mechan-

ism. The product may be a trivial act done in a moment or it may be a radical change in the whole program of my life. It is real work in both cases, and it is a very different kind of work from that of a blind passionate outburst or a simple reflex.

In the unconscious tropism or reflex the reaction is adapted biologically to secure some appropriate result, some end that is good for the animal, like coming in out of the rain or eating proper food or running away from danger. The difference between this and a voluntary act is that the useful or adaptive end is sought in the one case unconsciously and in the other case intelligently and purposefully. This is a big difference.

It gives us human folk the ability to lay out plans for future control of our circumstances, to make aqueducts, to dam streams for water power, and to invent machines for exploiting these natural resources. In the same way it gives us the ability to lay out plans for our own future growth in physical and spiritual power.

CHOICE

Here is a high-school boy with no particular interest in life except to have a good time. He takes up wireless and designs a home-made set. Out of this grows an ambition to be an electrical engineer, perhaps fostered by judicious encouragement of parents and teachers. It is all a natural growth. But he will never become a competent engineer by merely wanting to be one. That is beyond his power. It is quite within his power to make the decision that he will prepare to be one.

Now, of course, he may not settle the question at

all. He puts it off, and in that case it is not a choice. This putting it off indefinitely is in the end a decision, but not a choice. Evidently he does not want it badly enough even to make up his mind. But suppose he does make up his mind to become an engineer. This choice is a radically different event from what it would be if he did not look forward and make the decision in view of his understanding of the rewards of successful practice of the profession and the cost of qualifying himself for it.

It is not an uncaused action. We may be able to trace causal connections all the way through it. It is this understanding look into the future and of the probable results of the decision and the control of his present impulses and emotions by this intelligent appraisal of values imagined but not yet realized—this is what makes it a choice and not a reflex. The picture in imagination of wealth or renown that may come to him twenty years hence if he succeeds in distinguishing himself is a present act. It is a bodily process with a mental product. As such it is an efficient cause of the next act, which is his choice whether he wants to be an engineer or not.

He decides that he does and he knows that it will take him ten years of very hard work before he can earn his first fee, years of drudgery over mathematics and physics and all the rest. Now he puts his will-power to work and buckles down to tomorrow's algebra lesson instead of drifting out to the athletic field.

The boy's choice of what he wants to make of himself is a determining factor in what he begins to do today. He begins to acquire the necessary knowledge and technical skill. He begins with what he has now

of knowledge, skill, and character. If he notices lack of staying power and a tendency to fritter away his evenings in social trivialities, he proceeds to harden up his will-power by devoting most of his evenings to hard study. He deliberately shapes his personality for the job which he expects it to perform. This is a growth and it takes time, but it does yield the expected fruits in the end if faithfully followed out.

The boy probably does not reason this all out in this way. His parents may do most of that for him and boost him along day by day. But the boosting will do no good without some driving power from inside the boy himself.

There is nothing magical about these choices to be an engineer instead of a radio salesman or to study algebra instead of spending the afternoon on the bleachers. They are natural results of natural causes, some of which we can readily trace. But this does not alter the fact that the choice is the finest product of the noblest mechanism known to science.

WILL-POWER IS REAL POWER

The apparatus which exercises this voluntary control of conduct is chiefly in the cerebral cortex, one of whose functions, you will recall, is the bridling of the thalamic and visceral mechanisms of our elementary biological impulses. The strongest of these impulses are those associated with sex, and these are among the most primitive that we have.

In most other animals the sexual behavior is carried out instinctively, but in mankind these instincts do not work out automatically and unintelligently. There must be more or less conscious and deliberate

voluntary direction of the sexual impulses or disaster surely follows.

If this rational control is not kept up because the cortex is defective, as in imbeciles and some kinds of mental disease, then the lower sexual impulses may get out of hand and mess up the whole life of the unfortunate defective. This is not a reversion to a bestial condition, for the sexual life of brutes is very efficiently regulated automatically and unintelligently. Sexual debauchery in a man is not a reversion; it is a perversion; the normal balance of the cerebral control-works is impaired and he behaves as no brutes in their natural state ever do.

When an otherwise normal man relaxes the voluntary control of his sexual or any other impulses and enters upon a career of debauchery, he is not a brute, he is a fool; and as we have previously mentioned, a fool is a less competent animal than a brute. The brute is so adjusted to his environment that he can get along without much "brains." The man living in our present social environment cannot. The relaxation of intelligent voluntary control of the primitive (subcortical) impulses, whether of sex or any other sort, is prostitution of our birthright as human beings; for the capacity to exercise this control is just what distinguishes us from the brutes. We lack the mechanisms of instinctive control that other animals possess, and if we lose the voluntary control that we alone possess, we are less than brutes. We become *ipso facto* defectives.

This suggests another aspect of the story of the relation between cortical and thalamic types of working. Our most primitive sexual impulses are thalamic.

These, as we have just seen, are bridled and controlled by the cortex. But the cortex does more than this with them. It refines and elaborates them by weaving into the warp of our primal impulses a weft of intelligent control and then embroidering this fabric with a tapestry pattern of the finest ideals that imagination can conceive. So upon the basis of our crude sexual experience we have built up a world of romance, our finest sentiments of love, chivalry, tenderness, self-sacrifice, and devotion—another illustration of brains and viscera working in partnership and yielding the noblest fruits of the spirit.

The history of the fabrication of this composite apparatus of the spiritual life goes back a long way—farther than we can see in the dim mysteries of our animal ancestry. But the later chapters of this story are open before us, and they are easily read. They are written in romantic literature. The earliest sagas have some of it. The literature of medieval chivalry marks another phase. More recent romantic poetry and fiction mark its culmination. Just at the moment we seem to be in a back-eddy of this movement, for the most popular novels of the day seem to be more concerned with the cruder and more primitive features of the sexual life than with its more refined and ennobling aspects. Catering to pruriency and vulgarity will probably always be financially profitable, but the general level of popular tastes has risen slowly in the past, and doubtless it will rise again.

Voluntary self-control is effective because it is no penumbra of an ethereal spiritual presence floating around and into our personalities from the outside void. Nor is the feeling of voluntary power a smoke-

screen to conceal our impotence in the matter. It is an integral part of the personality that grows up with us as the organs of the spiritual life grow. It appears only when the cerebral cortex begins to mature. It grows with the elaboration of this cortex and its power and effectiveness are expressions of the action of this organ. This is real power because these are real organs capable of doing work the same as our muscles are.

Neither volition nor any other spiritual capacity is debased by this knowledge of how it works and how to develop and refine it. This power of self-control and self-culture by voluntary effort and intelligently planned exercise is the badge of our humanity. It is the most glorious thing we have.

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CHAPTER XXVIII

BODY AND SPIRIT

THE NATURAL HISTORY OF THE SPIRIT

WE COMMONLY think of human nature as body and spirit. How are these things put together to make of me a single personality? Or am I two things, or a trinity, or quadruplets, or just a jumble of miscellany? No, the unity of the normal personality is the most evident and incontrovertable thing in our experience.

The intangible and elusive nature of our spiritual experiences and spiritual values, such as artistic appreciations and moral sentiments, makes their precise observation and study very difficult and so we really do not understand them as well as we do the more accessible facts about our bodies and what we do with them that everybody can see if he wants to. Accordingly, we began our analysis of human nature with the study of bodily structure and behavior, for this gives a substantial framework for a natural history of man made up of experiences that are open to the world and that can be verified over and over again. Our spiritual life somehow fits into this frame and it seems to do so in an orderly and systematic way.

People in the past have seemed to be rather timid about undertaking a scientific study of the spiritual life. They shy off from it, perhaps because they are afraid that if we should drag our spiritual values out

of their dim mystical shadows and examine them too critically they might evaporate and disappear. But we have had considerable experience for a long time with our spiritual values and with their tremendous motivating power in human conduct. Our hopes and fears, our desires and aversions, our ideals and aspirations, our codes of etiquette, business, politics, and morals, our aesthetic and religious satisfactions—these do not seem to be so frail and evanescent as we supposed. On the other hand, they are hardy, perdurable, and puissant. We can afford to take a chance with them and bring them out into the full sunlight of frank discussion in perfect confidence that they will not only survive the inspection but be the better for an airing. We have no fears that, if we succeed in this quest, our spiritual values will be lost or obscured. Indeed, it would not be surprising if they should be enhanced and clarified.

After all, my spiritual nature is still human nature. Is human nature natural or supernatural? If natural, it has a natural history and this is worth looking into with naturalistic technique.

FAIRIES AND GHOSTS

Civilized mankind has a taboo thousands of years old against any search for a physical mechanism of the spiritual life. It is impious to suggest such a thing. For a successful outcome of this search is sure to knock the foundations out from under some of the most sacred dogmas of traditional theology and metaphysics. But theology is not religion and traditional metaphysics is not necessarily truth. Both medieval theology and platonic metaphysics have been rudely

jostled of late by scientific research and both seem still inclined to resent the intrusion of unwelcome facts into the settled calm of the sacred cloisters where their dialectic has flourished for centuries without contamination with vulgar material dross.

But genuine religious experience has up till now always survived the warfare of militant dogmatists and its hold on mankind is today stronger than ever, though it does not always go by this name. Facts cannot hurt it.

Some metaphysicians are quite up to date. But the popular metaphysics of the lay public, like the popular theology, is likely to be several centuries behind the times. A metaphysics whose sacrosanct traditions do not square with the accumulated experience of today cannot forever quench the light of honest inquiry. Fairies and ghosts belong to childhood. When we have grown up we put away childish toys. Or perhaps we preserve them in a museum cabinet for their sentimental or historical value.

MIND IS NOT A GHOST

Nothing will be gained here by raking over the dead embers of ancient fires of metaphysical controversy on the mind-and-body question; but there are some aspects of this theme which cannot be passed by in a strictly biological treatment.

Confronted with this difficult problem the temptation is strong to follow lines of least resistance and accept one of the two traditional ways out of the difficulty to which reference has already been made. The more popular way is to conceive the personality as divided into two air-tight compartments, physical

and spiritual, which somehow grow up together but don't mix. This conservative school, following the hallowed tradition of antiquity, declares in the face of evidence that the spiritual life has no organic relationship with the body, but is a mystic apparition of some sort, distinct in origin, in nature, and in mode of operation.

The chief trouble with this doctrine of parallelism is that obviously it is not true. The physical and the spiritual do mix. My body does affect my spirits and my spiritual life evidently does control, to some extent, the course of events in my body. I often do what I want to do, and the consciously formulated desire is certainly no negligible component of the conduct as physically executed. What I want to do, in turn, is not an uncaused event. Its causes can often be readily traced backward into physical events of the most obvious sort.

MIND IS NOT AN EPIPHENOMENON

The more radical school, again flying in the face of evidence, lightly dismisses spiritual experience as unreal or negligible because it does not fit into an oversimplified scheme of mechanistic biology. These radical behaviorists say that the working of the bodily mechanism that can be shown up by proper methods to any outside observer is my life and all there is of it. Any awareness of what is going on is mere froth on the surface of events, an iridescent film on the great stream of life which would go on just the same without it.

The reason for this curious attitude is plain enough. Reacting against traditional mysticism, which has

hampered scientific study of the human personality for centuries, they have followed the method of natural science as applied in the world of objective experience. This is right as far as it goes and it gives the best possible approach to a large part of human conduct. But conscious experience is not included in the rubrics of this traditional scientific method.

Being themselves bound by this tradition, they have not been able to recognize that the mechanisms with which they are familiar in physics and physiology are inadequate to do the work of human life and human society. And, what is still more important, they have overlooked the fact that we have known mechanisms in the human brain that are adequate for this task and that can be seen in operation performing it in every live man.

Most people are so sure that their conscious experiences are real and significant facts that they will go on believing in them anyway; and if there is no good scientific account of this experience they will turn back to traditional mystical accounts of it. The result is, as Dewey points out, that the one-sided account of the radical behaviorists perpetuates the very tradition which they are trying to destroy.

On this crudely mechanical view it is hard to see why consciousness is there at all, for it is certainly often very inconvenient. But common experience indicates very clearly that most of the big things that mankind has ever done were wrought with more or less clear-cut knowledge of the course and meaning of events and often with a thoughtfully planned program, with strong desires to achieve something and great satisfaction in its accomplishment. To say that

in building the Panama Canal the intelligence and enthusiasm of the engineers and the mental work of their computations were not causal factors does not seem like good sense.

If people really don't think but only think that they think, how did anybody ever happen to think of such a thing as to think that he thinks. This is the sort of a muddle that we get into if we try to explain away our introspective experience. When Watson says that the word "emotion" should be dropped from our vocabulary because "all that we mean by the word is visceral behavior," what has he gained? Only a trick of verbal simplification of a problem which is actually further confused by an attempt to distract our attention from the real nub of the question.

If these people mean that conscious experience is a reality which is significant in behavior, and that this mental life is the working of a bodily mechanism which can be studied by objective methods as well as by introspection, why don't they say so instead of ignoring the conscious experience altogether and insisting that the objective behavior and its bodily organs can tell us all that we need to know about our spiritual life?

It is time to recognize that our conscious experience is not satisfactorily disposed of by criticizing other people's mistakes about it or by pretending that when we have decided that mind is the working of the body there is no longer any mind to worry about. The mind has always been a troublesome factor in the scientific analysis of human behavior, but the inquiry so far has not been furthered either by dialectic or by ignoring the troublesome factors.

Of course there are many things that we do not yet know about how the brain works; but so there are about how digestion works or chemical affinity. If we were to assemble here all that we do know about the brain, all the recorded facts about its structure and its functions, it would be a surprising collection—and rather appalling. The record would make a big library of many thousands of volumes, more than any living neurologist has ever mastered.

Few people have any appreciation of the enormous labor that has been expended for centuries past in the accumulation of these facts or of the accuracy and minuteness of the examinations that have been made or of the number of people who have worked and are still working to complete this knowledge. This technical knowledge is hard to come by. It is also difficult to report it except in very technical language. But out of this welter of technicalities there is a slow increment of basic ideas that are not obscure, that anybody can understand, and that are worth knowing. To try to sift out these fructifying ideas is good sport.

A few years ago an eminent psychologist, in commenting on the failure of neurologists to tell him what he wants to know about what the nervous impulse is and similar general questions, remarked, "Surely the only difficulty in obtaining satisfactory answers to these questions is the lack of sufficient interest on the part of the men who are competent to carry on such researches."

This is rubbish. The interest is most acute and the competence of the men who are working at it is certainly as good as is that of the psychologists who

are working at their different jobs. If our psychologist would visit, as I have recently done, some of the most famous laboratories where nervous physiology is studied in America and Europe, he might be surprised to find that in the best of them the most eminent men in this field are working intensively on just the problem mentioned—what is the nervous impulse? And they are finding out too. The problem, in fact, is far advanced toward solution.

The trouble seems to be that these researches are so recondite that they must of necessity infiltrate into common knowledge and literature very slowly. It takes time for so abstruse ideas to digest and assimilate. After seventy years Darwin's contributions are even now widely misunderstood, and these ideas are simple in comparison with those related with the brain and its functions.

THE FUNCTIONAL VIEW AND ITS CRITICS

The bald and unequivocal declaration that our awareness is a function of the physical body in the ordinary biological sense—and this is our thesis—immediately calls forth a violent defense reaction with almost everybody, especially the philosophers and psychologists. Perhaps because it seems too simple and obvious to be probable. More likely because their minds are darkened by an ancient tradition from which they cannot break away.

Neither ancient nor very recent attempts to break with the traditional mystical notions about the mind in the interest of a more scientific treatment have been very successful. The trend among progressive thinkers at present is to attempt some redefinition of

mind in objective terms so as to facilitate its articulation with the rest of nature. This is easy. It is merely dialectic. But the subjective experience, the awareness, is left just where it was before—out in the inaccessible void.

The best of the recent statements of the problem that I have seen is Professor Patrick's book, *What Is the Mind?* In delightfully clear and simple language he outlines the history of the emancipation of psychology as a science from its former mystical wrappings and he shows how revolutionary the change has been for science as well as for philosophy. But after all, the goal reached by the philosopher is still just beyond the reach of the naturalist and one would like to bridge the gap.

Professor Patrick accepts the now-popular definition of mind as "the behavior of living beings as they adjust themselves to their surroundings in such a way as to maintain their integrity and satisfy their desires." This is an objective definition, for the word "desire" as here used does not imply any awareness of the impulse. Carr's expression would be better, "the satisfaction of the motivating conditions."

Psychology, it is explained, deals with the kind of mental activity just described, and "it is not to be confused with physiology, which deals with the functions of the various organs of the body in their relations to its inner economy." This definition of physiology is a pure fiction; there is nothing like it practiced in our physiological laboratories. There are important departments of both physiology and zoölogy whose subject matter is exactly the same as that of the sort of psychology here described.

The purpose of this sort of a definition of psychology seems to be to enable the philosopher and the psychologist—not the biologist—to detach the organismic functions, that is, those which concern the welfare of the organism as a whole, from the consideration of the functions of the separate parts. But it would be a poor sort of biology that limits its interest to the latter class of activities.

This logical and psychological separation of the functions of the whole from the functions of the parts is so widespread that I quote Professor Patrick's statement about it.

> We see then that mind is not matter in motion, and not a function of the brain. It is the characteristic activity of a unitary complex of an exceedingly high order. It is not a function of any organ or set of organs in the body but an activity of the individual as a whole in interaction with his physical and social environment.

This last clause, of course, is exactly what I have been saying throughout this book. But what is this "activity" but matter in motion? This matter must be somewhere and it must have some form. And of this matter in this form—partly in my brain and partly outside distributed throughout the whole reach of my sensory experience—my mind is a function in the ordinary biological sense of that word. And this is just as true of my awareness as adjustment as it is of my physiological reflexes as adjustment. The word-splitting has got us nowhere.

The statement that mind "is not a function of any organ or set of organs in the body" is true in the sense intended by the author; that is, mind—whether defined objectively as Patrick does or subjectively as I

do—is not the product of the activity of some particular piece of the body working in isolation and independently of other vital processes. Its organs are not insulated from their surroundings like an ice machine in a tropical city. That is not true of any biological functions, for the most essential feature of the vital process is "correspondence" or interaction between organism and environment.

When I say that the cerebral cortex is the specific organ of thinking in the same biological sense that our legs are specific organs of walking, I do not mean to imply that the isolated cortex can think any more than that legs alone could walk. Reference back to chapter xxi, where this comparison was made, will make this clear.

The organ is part of the whole organism and it has no biological significance apart from the welfare of the person as a whole; and the welfare of the biological unit which is myself is maintained by proper adjustments of my body within its physical and social environment. If I use my legs to go to the brook to get a drink or to the library to get a book, the physiological function of walking is defined not merely in relation with the "inner economy" of the body, but also in relation with the "correspondence" of that body with the environing things which motivate the act. These external relations include, in the first instance mentioned, the brook and all the meteorological and other events that produced the brook; and, in the second instance, they include the book, the library in which it is housed, and all the mental, social, and physical events that brought the book and the library into existence. These are parts of the total situation

to which as an organism I am reacting and within which my biological functions of correspondence with environment are carried on.

Legs are specific organs of locomotion. And the biological significance of these organs and their function is to get from some place to somewhere else in the interest of the welfare of the organism. In just the same sense the brain is the specific organ of thinking, whose biological significance is the welfare of the organism as a rational being in a particular physical and social environment.

The function considered as biological adjustment to environment may be looked at from two standpoints. First, in its external relations the organs of the function include the whole body and everything in the environment to which I am at the moment adjusting. Second, in its internal relations, some parts of the body—legs or cerebral cortex, for instance—have a more specific and indispensable part to play in the particular adjustment in question than do any other parts of either the body or the environment.

This is what we mean by saying the cerebral cortex is the organ of thinking; it is the particular part of the body whose activity is essential for the execution of those types of adjustment to a total situation in which the awareness of the situation (or part of it) is present. The awareness is a biological function of this sort of activity, that is, it is the operation of a particular arrangement of matter working in a way determined by its structure and the situation within which it is operating. This, as we saw at the beginning, is characteristic of the output of all mechanisms. The awareness is a function of a mechanism in just

the same sense that a magnetic field and a reflex are functions of mechanisms; the different mechanisms deliver different products.

In the final chapter of Patrick's book, entitled, "Formative Forces," there is one more passage which should be quoted as evidence that the author really sees his problem with a broader view than the bit of dialectic already cited might indicate.

So it appears that a mechanistic world-theory in the light of present day knowledge loses much of its former significance. It has no special terrors. Matter is no longer dead and inert, and in all organisms the most significant thing is not the units but the organization itself and its emergent properties. In other words, *a mechanistic world-scheme today is no longer mechanistic in the older sense* [italics mine].

Here science and philosophy come into perfect accord. They are talking about the same things in the same language, and these things are matters of verifiable experience.

This is also the theme of another great book by a distinguished philosopher. Whitehead, in his *Science and the Modern World*, outlines his argument as involving "the abandonment of the traditional scientific materialism, and the substitution of an alternative doctrine of organism"—a thoroughly scientific procedure, though arrived at by a route which to the present writer seems as roundabout and scientifically objectionable as Patrick's.

The tendency in recent times has been to escape from mechanism by ascribing the behavior of living things to some supermechanistic agency called "organism." But, as already pointed out, more critical

examination shows in inorganic nature some of the same organismic features and so just now we witness a curious reversal in philosophic thought. The attempt to reduce the organic to the inorganic has failed. Now, since the unity of nature is more firmly established than ever, the only recourse is to elevate the inorganic to the organic plane. "The whole universe is regarded as made up of organisms."

The way out of this curious dilemma is not to say that the mechanistic treatment is scientific and the organismic treatment is philosophical and that the two overlap completely but cannot mix, which seems to be Needham's idea; for the doctrine of organicism, if it is true, must rest on factual evidence and it must stand up under critical scientific examination.

Why are we so afraid of mechanism? It is not dangerous if you do not ignorantly meddle with it. Our refusal to admit it in human affairs would be tragic if we lived up to our professions. But practically, whatever our philosophy, we adjust mechanistically to a mechanistic world. To clear up the muddle all that is necessary is to recognize that the mechanisms by which we humans make our adjustments are radically different from those of planetary orbits and ameboid tropisms but not separated from them in the system of nature. We do not need to look for a god in the machine in either case.

THE UNIQUE QUALITY OF CONSCIOUSNESS

Objection has been voiced against this obvious and naive conclusion of the biologist on the ground that the conscious or subjective experiences that comprise our spiritual life are so different from those other

kinds of behavior that we can observe objectively and that can be verified by many people. They are so unique, so intimate and private, that they must be classed apart.

Yes. They are different. Of course, the spiritual functions are unique. So are all the others. If it were not so we would not separately name them, and these are the most peculiar of all. They are as distinctive as their organs. We breathe with lungs and walk with legs and think with brains.

That is what we have these organs for, and each is structurally adapted to perform its own function. The peculiar thing about the function of thinking is that the thinker is aware that he thinks and he knows what he is thinking about. This is the distinctive peculiarity of this kind of a function. I do not know why this is so, but I accept the evidence that it is so, just as I accept the evidence that a tuning fork vibrating 256 times a second emits a tone that I call middle C and a fork vibrating twice as fast gives a note an octave higher. One of these things is no more unintelligible to me or unbelievable than the other, and both of them are attested by authentic experience. Some day we may understand both of these mysteries better. In the mean time we may as well accept them both and do what we can with them.

The unique quality of the spiritual functions is, of course, their intimate private and personal nature. This is what makes them so hard to study and to understand. Yet the relations of these experiences to other natural events can be studied scientifically—their causes and consequences, the conditions under which they appear, and the bodily organs concerned.

Moreover, these experiences can be controlled to some extent under conditions of scientific experimentation, and they may be repeated and verified with even more precision than can some observations in the realm of the objective physical sciences.

I can find out what external conditions must be set up in order that I may perceive a red color, and I can prove that I always do perceive a red color in that set-up of conditions and that in the same set-up you tell me that you also perceive a red color and behave as if you do. This can be verified as often as you like. I have observed that certain external events generally make me angry and I can examine both the mental and the physiological aspects of that interesting experience as often as I want to or think it is good for me to do it. Indeed, I can go further and prove that in certain states of physical exhaustion or nervous irritability I am much more likely to get angry than when I am rested and in good tone. I can even learn to control my anger and replace it by some quite different emotion, so that instead of damning out my stupid porter every day I laugh at him.

The verification and control of mental processes is harder than it is to do this in the case of finding the weight of a piece of brass or its chemical analysis, but not so hard as it is in the case of the weather or the fall of meteorites. The difficulty of a problem should be no bar to its investigation. The easy things have been done long ago. The problems of consciousness are probably not inherently more difficult than is the task of measuring the diameter of a star 192 light-years away, and this has been done. But we have to learn how to do it, and this, as already pointed out,

we are not very likely to do as long as we hold a belief that the problem is insoluble because consciousness is some sort of mystical "non-physical entity."

THE CONTENT OF CONSCIOUSNESS

We have commented on the fact that the peculiar thing about cortical activity is that part of it is conscious. We know what is going on—or some of it. Now the cortex is not conscious of itself as acting. We do not directly experience nervous conduction or any other physiological process as such.

I would never know that I have a brain or nerves unless somebody told me or I inferred it for myself from what I have learned about other men's nervous systems in the dissecting-room. So also you will never know that I am conscious unless I tell you or you infer it for yourself by watching my behavior and comparing it with your behavior when you are conscious.

This indirect way of getting at knowledge about the insides of our bodies and the insides of other people's minds is not as direct and satisfying as the way we get at the insides of our motor cars; but it is the best way we have and we have to put up with it. It is good enough to tell us a great many things that we want to know if only we use it skilfully. But we have to be careful or it will tell us many things that are not so, because inference is never as safe as direct observation.

The newspapers the other day carried a story of a man who tried to commit suicide by shooting himself through the heart—on the left side where every proper heart should be. But in this case it was not a proper heart. It was on the right side and the bullet failed

to pierce it. The unfortunate man will probably get well.

Most hearts are on the left side, and all men who have grown up to adult life and whose bodies have been dissected have more or less brains in their skulls; and the evidence is pretty good that these men during life did more or less thinking with such brains as they had.

No, our awareness is not of our brains or of their physiological functions of nervous conduction and so on, but of other and quite different events that are going on outside of us or inside of us, or perhaps of things that do not go on at all anywhere, of imaginary things or things that we hope or expect to happen by and by.

This is all very mysterious and I cannot tell how it is done. I just accept the evidence that this is what is done. Some day we shall probably know more about the actual workings of the thinking machines inside of our skulls.

Even though we do not know how the brain thinks, we know as surely as we know anything in biology that it does so. And we know a great deal about the thoughts that it thinks, for they are our thoughts, the most direct and immediate experiences that we have. These thoughts and their accompanying feelings can be attended to as they come and examined critically in retrospect, and this sort of experience makes up the greater part of the science of introspective psychology. The introspective examination of our own conscious experiences is, accordingly, one practicable method of finding out how the brain thinks, for this gives us

directly the product of the activity, the end-result of the process.

I may learn to drive a motor car and have it under perfect control without knowing anything at all about how the steering gear or any other internal parts are made or how they work. So I have learned to use my brain by trial and error, with more or less skilful guidance by my teachers, and I have got my bodily machine under fairly good control; and this I did before I learned anything at all about the insides of my brain or my body.

One day I took my motor car apart and I learned a great deal about how it is put together and how parts of it work. As long as everything is in running order I do not drive it any better for this experience; but the gratification of my natural curiosity about the mechanism came in handy later when it stalled on a hill, miles from a repair shop. From the symptoms which it showed before it wheezed its last wheeze I could guess which one of several things might be wrong because I had learned something about how these things are normally done. I looked under the hood, found the trouble, repaired the damage, and the car went on completely cured.

I have had a similar natural curiosity about how the brain works, and for the past thirty years I have been lifting up the top of the skull, the calvarium, of men and various other animals and examining what is inside. This kind of knowledge does not help me to think more logically—not directly—but it does help me to diagnose nervous disorders and sometimes to assist in effecting a cure.

The end-result of the activity of a motor car is mileage. The end-result of the activity of the brain is thinking. Experience with this end-result and knowledge of the mechanism which brings it about are both necessary if we are to have our machines under perfect control and keep them so in all weathers and in all emergencies.

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CHAPTER XXIX

VALUES

AESTHETIC VALUES

IN EVALUATING works of art most of us prefer the original individually designed and executed product of a master's skill to a replica of it, no matter how perfect the technical execution of the latter may be. We like unique and exclusive designs in our clothing, our pictures, our dwellings, and all the furnishings that contribute to the enhancement of our appreciations of the things which dignify and enrich life.

The touch of a master-hand cannot be imitated by another nor reduplicated by any crude artificial mechanical process. Every good etching shows the artist's individuality, not only in the graving of the plate, but also in each impression made from that plate. No two are alike. We prefer a remarque proof to any process reproduction of it.

MACHINE-MADE VALUES

The natural mechanisms which have been surveyed in the preceding chapters all make individual products; they do not manufacture in job lots. No two sunsets are alike, no two oak leaves, no two puppies, no two babies. The individuality of the output of the vital mechanisms is its outstanding feature, and this reaches its consummation in the human machine.

The human personality, historically considered, is a product of that vast organic mechanism which we symbolize by a scientific name, "the Genus Homo." From the standpoint of the worth of that product, its value, it may be considered as a work of art, good or bad as the case may be.

Science is not indifferent to these values. They have meaning and interest for the scientific man, not merely because as a man he is more than a recording and computing machine, but because the scientific method is inherently a method of classification and selection and the selection may be made in terms of any values we like. It must be made in terms of some values. In most of the so-called "applied sciences" commercial values are explicitly recognized. In the less obviously practical "pure" sciences the values sought are more intimately personal. The investigator does what he does because he wants to and perhaps for no other reason and at great financial sacrifice. The values are always there and they motivate the research, else it would not go on.

From this it follows that the output of the individual human machine, whether it be engaged in scientific investigation, business, or pleasure, is motivated by values more or less clearly recognized as such. These motivating values, our needs, wants, desires, and aspirations, are therefore so wrought into the living fabric that the scientific analysis of that fabric cannot ignore them. Indeed, they may become objects of scientific research, and they must be before the science of human biology can be fully rounded out.

Though our human values are machine-made,

they are nevertheless intimately personal and individual. That is why their scientific study presents so great difficulty that most humanists and economists have dismissed them as inaccessible by the scientific method. It is true that they cannot be attacked directly by this method; yet an indirect approach is possible, for these values are related in manifold ways with other natural things and events and these relationships can be investigated scientifically. The case is not so hopeless as it has been supposed to be.

SCIENCE AND VALUE

It is a popular complaint that science has no place for spiritual values and that scientific training tends to blunt the finer sensibilities and appreciations.

The answer to the last point is a flat denial of the truth of it. The most highly trained scientific investigators rank up with any similar group of successful men the world over in all the finer spiritual qualities. No one widely acquainted with these men will question this statement.

A training which dwarfs or impairs these spiritual values is not truly scientific. Pseudo-science will do this, and there is plenty of that around. If you find anybody with good scientific training whose spiritual values have been stunted or distorted, it will usually be evident upon examination that the responsibility for the mischief lies, not with his science, but with a faulty philosophy.

On the other point, it is true that mechanistic science in the past has generally ignored the spiritual life as lying outside its domain. But this arose from a limited and defective notion of the real nature of

mechanism, of the spiritual life, and of the scope of mechanistic biology. Our conclusion is that all life is mechanistic, the best of it as well as the worst of it, and is a legitimate object of scientific study.

We have not destroyed or impaired any of our finer spiritual values and appreciations by finding out how we do these supremely important and satisfying things any more than a landscape painter impairs his aesthetic appreciations by learning the rules of perspective and the chemical laws of the composition of pigments. These are tools of his spiritual life. So are his brains and his ductless glands.

In the light of these considerations let us next review briefly the argument and see where we stand as mechanists with reference to the problem of values as motivating agents.

CHAPTER XXX

HUMAN BIOLOGY

THE MECHANISTIC WORLD

IN DEFINING what we mean by a mechanistic world we found it necessary to enlarge the popular idea of machines to include everything that performs work by natural agencies in accordance with natural laws. Having arrived at this enlarged conception of mechanism, we conclude that all vital functions are mechanistically performed and also that conscious acts are vital functions performed by definite physical organs. All life, including the mental or spiritual life, is a mechanistic process.

Let it be repeated, this is a scientific conclusion based on factual evidence, that is, upon our experience of nature and of human nature. It fits that evidence better than any other hypothesis that has been proposed. It by no means explains everything. We have no answer at all to the question, How does a machine think? We do have evidence that it does so, and the question proposed is probably not insoluble. All we can say is that it has not yet been solved.

If we adopt as a working hypothesis this radically mechanistic view of life and of mind, then all of human nature can be explored by the scientific method, using data and laws of physics, chemistry, biology, and introspective psychology wherever they prove to be applicable. The human personality is not dismem-

bered into a physical body and a metaphysical spirit, but it is an organic whole every part of which can be examined by scientific methods as fast as we learn how.

THE SCOPE OF HUMAN BIOLOGY

Our conclusion that thinking is a mechanistic process, a natural function of physical organs, breaks down the last barrier which formerly blocked the path to a scientific study of human nature—all of it, not merely the parts of our nature that we share with beasts. We have not yet learned how to do this very well, for the sciences of man's mental processes—what we call the spiritual life—are still in their infancy. But at any rate we can take courage from the progress already made and hope for more substantial gains in the immediate future. This prospect of a renaissance of human biology is alluring.

The world of inorganic nature, the world of living things, and the world of man in his loftiest flights of creative imagination and his most refined spiritual experiences and moral triumphs is one nature and all of it lies within the scope of natural science.

But science has a long way to go before it can fully possess this promised land, and fortunately we can by other methods reach out far beyond the contracted horizons of our verifiable scientific knowledge. The fields of imaginative art, of appreciation of aesthetic and moral values, of philosophy and religion, offer satisfactions which do not need to wait upon scientific confirmation.

Yet, let it not be forgotten that human nature, even in these noblest of its achievements, is still part of that larger nature which has been surveyed in this

work. Our most refined spiritual activities are not in conflict or out of tune with those more elemental natural processes which have already been explored and systematized in our science of today.

It has been pointed out that even faith should be founded on knowledge and knowledge need never impair faith. Faith supplements knowledge; it should never try to replace it. A faith which fears knowledge and which does not square with experience has something radically wrong with it and is to be looked upon with suspicion.

CHANGING HUMAN NATURE

We are told so often that you cannot change human nature that we have actually come to believe it. There has never been a more ridiculous or mischievous superstition in the whole history of mythology.

Changing human nature is exactly what has been going on from the dawn of the race, for the most part blindly by unintelligent muddling. We can do it better by attending to it and the laws of it. It can be done slowly by eugenic improvement of the breed, and very rapidly by education and other social forces. Advances made by both of these methods are enduring and relatively stable.

We have proved that both of these ways of changing human nature are practicable enterprises by doing them. We can do them better when we learn more about how to do it. Indeed, we can do them better now by more intelligent application of what we already know any time that we want to.

Our minds are better minds when we understand them and their organs better. In fact, this sort of

knowledge is our only hope of gaining satisfactory control over mental work, mental culture, and mental evolution. This is worth working for and it is not an impractical ideal.

THE SPIRITUAL LIFE

Our conscious life is genuine life. Our thinking, our emotions and sentiments, our volitions, our hopes, aspirations, and ideals, our imaginative excursions, our faith and reverence—these are all vital processes. They are things that we do with our bodies. When they are done well they are the finest things in the world. We can do them better if we try because trying is also a vital process. It gets results because real organs are working, organs that can be strengthened by exercise and trained.

It will do the moralist no harm to learn more about the natural laws of the spiritual life, the rules of moral culture and education, the apparatus and technique of refining ideals of conduct and character, the way to go about it to develop will-power and self-control, and the bodily organs that do these noblest of our human achievements.

We lose nothing and we gain much by supporting our natural cravings for spiritual power, our aspirations for finer experiences, our appreciations of spiritual values, and our gropings for answers to the great riddles of life, of time and eternity, by such scientific evidence as is available.

We have only to recognize that my spiritual life is a natural function of my natural body and to think this thing through to see that these spiritual activities and the bodily organs that perform them are real

causes of behavior and real creative agents in the fabrication of my personality. They and their organs grow up with us, and the capacity for self-control and self-culture can grow no faster than the organs which perform these functions grow, and no farther.

Part of our human nature came to be what it is naturally and unwittingly just as dog and ape nature did. Our higher spiritual values come naturally but not unwittingly. They must be sought. They will not come at all unless we want them and attend to their culture. The original sources of our scientific inventiveness, of our self-control, of our self-culture, and of our higher spiritual values in general are to be found in our animal ancestry. But the actual fabrication of these tools of civilization came only when the human kind of mental capacity emerged. The clear recognition of what these tools are of course facilitates their use and accelerates their culture.

Shaping a personality, character-building, this is the noblest creative power of man. There is much that is still obscure here, but we already know enough about the procedures to engage in this kind of constructive work with excellent results. The tools are family and public education and other social agencies and, most important of all, the formation by each individual of the ideals of character and conduct and personal effort necessary to attain them.

The ability to forecast the future, to foresee the probable results of a present act, to decide on a course of conduct in view of future contingencies, consciously to desire something and to reach forward to attain it, to build up an ideal of what I want to do and to become in the future, so to shape my present

conduct as to approach that ideal, to enlarge the field of my desires to include the welfare of the community in which I live as well as my selfish gratification, to socialize my ideals, to evaluate experience in terms of both personal enjoyment and the happiness of others and to strike a balance between these which is good for all of us, to translate uncritical wants into ideals of value and to control present conduct in terms of the relative worth of these values, to learn to lay out a deliberate program of self-culture and to subordinate other motives to this purpose, to cultivate ambition and aspiration for better things, and to enjoy the satisfaction of successful achievement—these are things that we all do. This is not theory. There is nothing mystical about it. It is common experience.

Is it of no account to us that we can do these things, that we can take a part in shaping our own personalities, that we know that we are doing it, that we can imagine the design that we wish to invent or the character that we want to achieve, that we can foresee the effect of every choice upon the further course of our progress toward that ideal, that we can watch our progress from day to day with satisfaction or disapproval, that we can learn from past failures to choose more judiciously next time, that we can enjoy the pleasure of success, that we can hold ourselves in line of further progress by fear of failure and hope of future triumph—are these experiences negligible factors in our lives?

These spiritual exercises are real facts. They are real functions of real bodies. They are results of causes, just like everything else that our bodies do. And in turn they are real causes of behavior. They

are part of the apparatus of human control, and they are the most significant part. They make us what we are—the dominant members of the animal kingdom. We control the face of nature, we control dumb brutes, we control ourselves—not completely in any case, but well enough to enable us to hold our place as lords of creation.

IN CONCLUSION

It is clear that myth, magic, mysticism, religion, art, and science are all good for something, each in its own place and time in the progress of the development of human culture in the race and in the growth of spiritual competence in the individual. It is a good plan to know just what each one of these is good for and not mix them up uncritically.

It is equally important to recognize that these spiritual activities in their more highly elaborated forms are not incompatible or in conflict or rivalry with one another. In the normal well-balanced life they supplement and support one another.

The survey of human nature here presented is obviously partial; the approach is from only one side and with one technique, that of natural science. Many things of humanistic interest are necessarily left out of consideration, not because they are unimportant, but because they do not lie within the scope of this treatment.

It is clear, however, that the scientific view of human nature gives a wider outlook than is generally recognized and many of our capacities and interests that are usually regarded as beyond the scope of the scientific method are seen to be quite within our reach

from this side. There is no conflict, and there should be no discord, between the values which we can now set in their places within the order of nature and those others which are equally genuine and perhaps more satisfying but whose scientific analysis still eludes us. Faith—intelligent faith—helps us across some of these dimly lighted fields.

We have faith in the order of nature. We have faith in ourselves as parts of the order of nature. We have faith in our experiences as reliable guides to conduct, and the wider the experience the more reliable it is. We have faith in the seen and the unseen, but both of these faiths need constantly to be checked up by all the other kinds of experience that we can get. The scientific method is only one way to enlarge and rectify our experience. It is a safe way and a satisfying way. The claim here made for it is that it will take us farther into the domain of the spiritual life than some of us have supposed.

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(Names of persons are in Capitals and Small Capitals)

PRINTED IN U·S·A